Ossian R. Butterfield

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ECONOMIC ANALYSIS OF RECOVERY BY CYCLING OF A GAS CONDENSATE RESERVOIR

by

OSSIAN R. BUTTERFIELD
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Ossian R. Butterfield
Commander,
Civil Engineer Corps,
U.S. Navy

Austin, Texas
August, 1964

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CHAPTER I

INTRODUCTION

The frequency of discovery of gas condensate reservoirs, as well as their importance to the industry, has increased greatly in recent years with the trend toward drilling into the deeper environment of higher temperatures and pressures. Craft and Hawkins[1] point out well test data confirm this trend as shown in Figure 1. This graph shows the discovery trend for 17 parishes in southwest Louisiana. The reservoirs were separated into oil and gas or gas-condensate types on

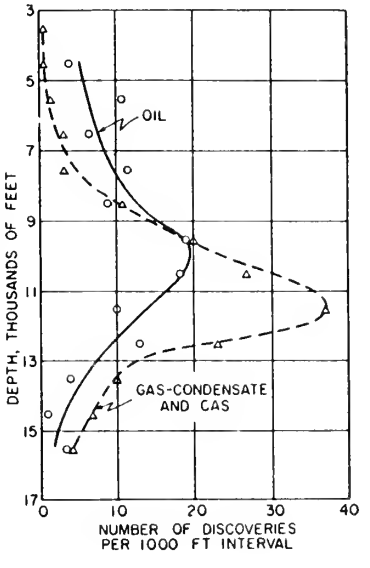


Fig. 1. Discovery frequency of oil and gas or gas-condensate reservoirs versus depth. (Craft and Hawkins, Applied Petroleum Engineering.)

the basis of well test gas oil ratios and the API gravity of the produced liquid. While oil discoveries predominate at depths less than 8000 feet, gas and gas-condensate discoveries predominate below 10,000 feet. The decline in discoveries below 12,000 feet is due to the fewer number of wells drilled below that depth rather than a drop in the occurrence of hydrocarbons.

Many of these high pressure condensate reservoirs are discovered in conditions above their dew points. With pressure reduction, when placed on production, they allow retrograde condensation of the valuable heavier hydrocarbons within the reservoir rock. Once condensation has taken place within the reservoir, this liquid cannot be produced without considerable expense. The mechanisms by which this condensation may be retrieved is either by revaporization or by repressurization by injected dry gas. However, several pore volumes of dry gas must usually be injected before sufficient revaporization occurs, making this process costly. Even then, the dry gas may not sweep all the volume in which condensation has taken place. In order to retrieve this condensate, which is many times more valuable than the gas itself, or to prevent its condensation within the reservoir, it is necessary to investigate the possibility of dry gas cycling and pressure maintenance.

Cycling of the dry residue gas may act to maintain the pressure in the reservoir at or near the dew point, thereby

preventing the occurrence of the retrograde condensation phenomena. It may also tend to revaporize the condensate and sweep it, along with the cycled gas, out of the reservoir.

Even though it is apparent that cycling a reservoir which is susceptible to the retrograde phenomena will produce more of the valuable hydrocarbons in place, the economic factors involved are all important in deciding whether to invest in this procedure. Roughly, a reservoir that contains as much as fifty barrels of condensate per million standard cubic feet of gas is a good prospect for gas cycling. On the one hand, the dry gas sales will be postponed until the cycling is practically complete, resulting in decreased present value of the gas. However, it is generally possible to produce the condensate faster, hence earlier, when cycling is adopted and more dollars are generally obtained due to the increased ultimate recovery. The purpose of this thesis is to evaluate whether or not these advantages are worth the greater investment involved for the field studied.

Data are obtained from an actual field on the Gulf Coast of Louisiana containing approximately 600 billion SCF of gas. The size of the reservoir was determined from geologic data and from production data to date. Future prediction of reservoir performance was made for pressure depletion, normal cycling and pressure maintenance methods of exploitation. An economic comparison of the cases studied is presented.

CHAPTER II

DISCUSSION

A. Nature of Gas Condensate Reservoirs

Gas reservoirs are defined as having a lean gas, containing a minimum amount of the heavier hydrocarbons, where the composition of this produced gas does not change with pressure reduction as the reservoir is depleted. Oil reservoirs range in gas content from zero, or dead oil, to a gas-oil ratio of a few thousand cubic feet per barrel. In gas reservoirs, on the other hand, the liquid may be vaporized into 100,000 cu. ft. per barrel or more. Gas condensate reservoirs are classified between these two extremes. Gas condensate reservoirs, or distillate reservoirs as they are sometimes called, usually produce light colored or colorless stock tank liquids with gravities above 45 degrees A.P.I. at gas-oil ratios in the range of 3,000-100,000 SCF/bbl. The production from these reservoirs is predominately gas from which some liquid is condensed in the surface separators, which phenomenon gives them the name gas-condensate.

Another definition of the three types of fields described can be derived from an interpretation of the pressure-temperature phase diagrams. (See Figure 2 for a typical diagram.) Whenever a reservoir fluid is discovered at a temperature above the

cricondentherm, or maximum two phase temperature for the fluid, the composition of the produced fluid will not change as the reservoir is depleted since the reservoir temperature can be expected to remain fairly constant (Path $A\text{-}A_1$ on the diagram).

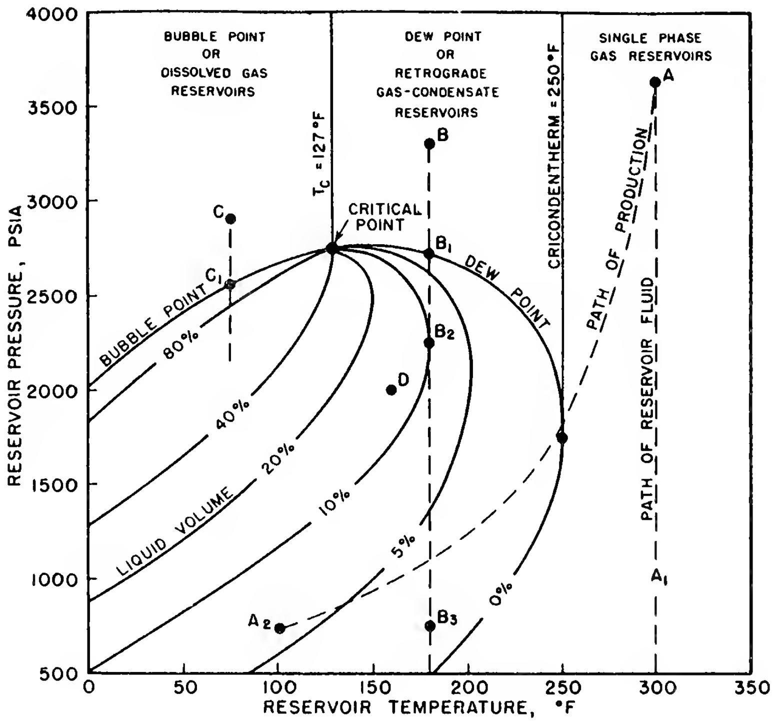


Fig. 2. Pressure-temperature phase diagram of a reservoir fluid. (Craft and Hawkins, Applied Petroleum Reservoir Engineering.)

There may, however, be liquid produced as the fluid flows up the well bore and into the separators if temperature reduction below the circondentherm occurs within the tubing string (Path $A\text{-}A_2$ on Figure 2). If, on the other hand, the reservoir is

found to be at a temperature below the critical temperature (T_c) and pressure above the bubble point, the reservoir would be in a one phase liquid state. This is called a bubble point reservoir and the fluid will remain a liquid although as the bubble point pressure is reached, with pressure depletion in the reservoir, gas will come out of solution in the oil and will be produced along with the oil in an ever increasing quantities (Path C-C_1 in Figure 2). In dew point or retrograde gas condensate reservoirs the reservoir fluid exists at a temperature between the critical temperature and the cricondentherm and at a pressure above the dew point pressure of the fluid. In this situation, when the pressure declines, composition of the reservoir fluid, which may be termed gas in this state, will remain the same until the dew point is reached. At this point as the fluid expands isothermally, a liquid begins to condense out of the gas and will adhere to the walls of the rock, tubing, etc., leaving a gas leaner in the heavier hydrocarbons to be produced. The term retrograde is given to this phenomenon since one would expect vaporization to take place with a pressure decline rather than condensation. At some intermediate pressure, between the dew point and abandonment, this retrograde phenomenon will reach a maximum, below which pressure the condensate will revaporize into the gas. (Pressure-Temperature phase relationships for gas-condensate reservoirs are shown on Figure 2 by the path from B to B_3.)

B. Retrograde Loss of Condensate

Liquid that is condensed inside the reservoir rock remains immobile in the usual case and therefore is lost to production unless or until revaporization can take place either by further pressure decline, repressurization, or by sweeping with a dry gas. The alternative to revaporization of this condensed liquid is to prevent it from condensing in the first place and this possibility leads to the investigation of pressure maintnenace by injection of dry gas into the reservoir.

C. Experience in Gas Cycling

In general, the gas with the greater condensate content exhibits the greater condensate loss upon pressure depletion so usually it proves to be the more profitable reservoir to cycle with gas. In gas cycling the condensed liquid is separated from the wet (produced) gas in a gasoline plant or other surface facilities. The residue or dry gas is then re-injected into the reservoir where it maintains the reservoir pressure and also serves to drive the wet gas toward the producing wells. This procedure is continued until the dilution by dry gas at the producing well renders the operation unprofitable at which time the reservoir is blown down, or allowed to produce normally through pressure depletion. During this pressure blowdown not only will the lean gas in the reservoir be produced

but also additional liquid may be recovered from both the dry gas invaded zone and the uninvaded portion of the reservoir.

Bowers[2] has shown that cycling in the Grapeland Field, Houston County, Texas, resulted in a recovery of seventy-five per cent of the initial butanes and heavier hydrocarbons in the reservoir, while straight pressure depletion would have recovered only thirty-nine per cent of the initial butanes--plus. The liquid that could have been recovered by pressure depletion, then, was only fifty-two per cent of that which was actually produced by the cycling process. In this example it was shown that the ultimate liquid recovery was reached in approximately eleven years but twenty-one years would have been required by straight depletion, thereby making the present worth of the liquid products much greater with gas cycling.

In a study of the Krotz Springs Field, St. Landry Parish, Louisiana, Robertson[3] predicted that twenty per cent more condensate could be recovered by cycling, resulting in a gross cash gain after taxes of $2,000,000 for the twenty-five year period studied.

T. W. Brinkley[4] concluded that benefits in improved recovery of stock tank condensate by pressure maintenance methods may be as great as 300 per cent in rich condensate reservoirs but grade progressively downward to negligible benefits for the lean condensate reservoirs with GOR's greater than 300,000 cubic foot/bbl.

Although cycling may appear to be the ideal solution to the retrograde condensation problem there are other factors that may make this procedure uneconomical. The deferred income from the dry gas sales may prove to be a significant factor in the economic analysis of the field. Another economic consideration is the added investment required for additional injection wells, gas compression and distribution system to return residue gas to the wells and for a liquid recovery plant. Also, it must be remembered that even with gas injection at a pressure above the dew point all of the liquid hydrocarbons may not be recovered.

Three different recovery factors must be applied with gas cycling. The microscopic displacement efficiency is approximately 70 to 90%. The volumetric sweep efficiency, or the per cent of initial pore volume invaded by the sweeping gas to abandonment of the producing wells can vary from 50 to 90%. Finally a permeability stratification factor must be applied to take care of the problem of gas sweeping through the more permeable strata and reaching the producing wells before the tighter stringers can be swept. The overall condensate recovery factor for a gas cycling project is the product of these three factors. On the plus side of recovery by cycling is the fact that additional liquid is produced during blow-down from the less permeable or unswept portions of the reservoir as these products bleed into the

more permeable streaks and ultimately to the wells. Also the efficiency of extracting condensate from the wet gas is higher with the type of separator plant that is generally used in a cycling project.

Any reservoir exhibiting retrograde properties and having a richness of 50 bbls/MMSCF of condensate is a good prospect for cycling of the dry residue gas to improve recovery. Each reservoir, however, is an individual case and, as such, requires a separate study. Variables such as permeability stratification, reservoir geometry, gas properties, and market availability can team up to make one reservoir an extremely profitable enterprise while another may prove entirely infeasible. This thesis presents the study of one field based on the fluid properties and geologic structure of that one field.

CHAPTER III

DEFINITION OF THE FIELD STUDIED

A. Development of the Field

Production from this field began in January, 1961 and from that time two to three wells have produced continuously as shown in Table II. The pool is one in which higher than normal pressures are encountered. It has been obvious from the low gas-oil ratios measured that the produced gas was rich in condensate. By January 1, 1964, a total of 20 billion standard cubic feet of wet gas had been produced from the two wells completed in the zone studied. The pressure had dropped from an estimated initial pressure of 8838 psia to 8100 psia as shown in Figure 7. Based on these production data, calculation of the initial gas in place yielded the value of 606.9 billion standard cubic feet. These values form the basis for future performance predictions from the base date of January, 1964.

B. Structure and Reserves

Interpretation of available geologic data indicates a deep-seated salt domal structure. Producing depths at which this study was conducted were from approximately 11,300 to 11,600 feet. A structure contour map of the top of the producing formation is presented as Figure 3. The productive

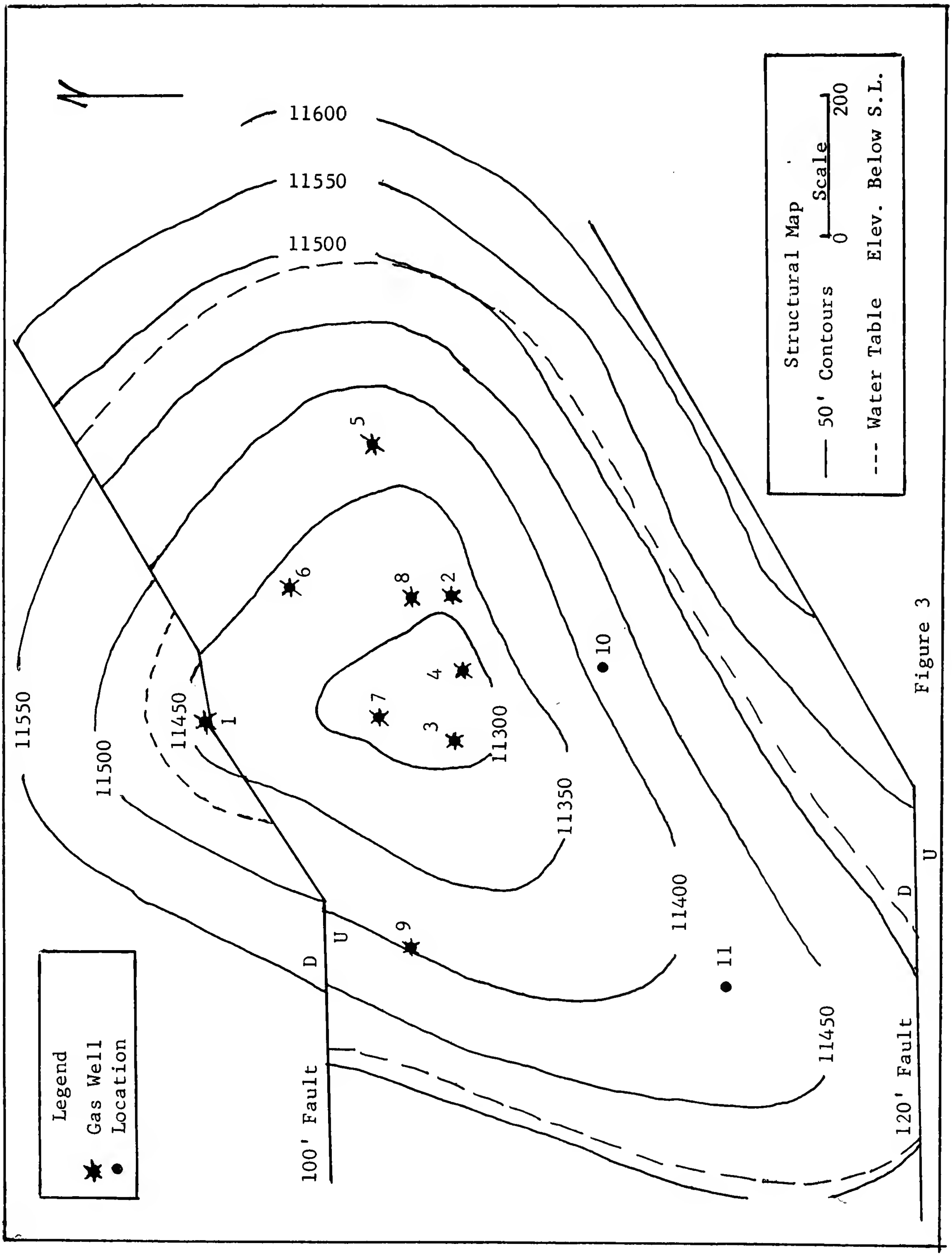

Structural Map
Scale
0
200
— 50' Contours
--- Water Table
Elev. Below S.L.
Legend
Gas Well
Location
11600
11550
11500
11450
11400
11350
11300
1
2
3
4
5
6
7
8
9
10
11
D
U
100' Fault
120' Fault

Figure 3

interval is taken to be a shaly-sand with intergranular porosity.

There are a total of nine wells drilled through the formation studied and from which data are available from various kinds of logs. Porosity was determined using micro-logs from some wells and sonic logs from others. The porosity throughout the formation is fairly constant, varying from 25% to 29% in the pay zone. Although shaly streaks were noted, this fact was taken into consideration in counting sand, wherein the shale sections were discounted. For purposes of the material balance calculations an average uniform porosity of 28% was used.

Electric logs or induction-electric logs were available from all nine wells. Three of these logs are shown in Figure 4. These logs were used to compute formation water resistivity using the Spontaneous Potential Curve. Water saturation was calculated from the induction log or lateral curve as available. Water resistivity was found to be approximately .03 ohm-meters at formation temperature and this value was used throughout the field. Computed water saturation tended to vary from 8-10% near the top of the gas zone to about 25% nearer the bottom of the pay and it grades to 100% water saturation in those wells where a gas-water contact is observed. A value of 20% water-saturation was used for the entire formation as being the weighted average value.

WELL LOG CORRELATION

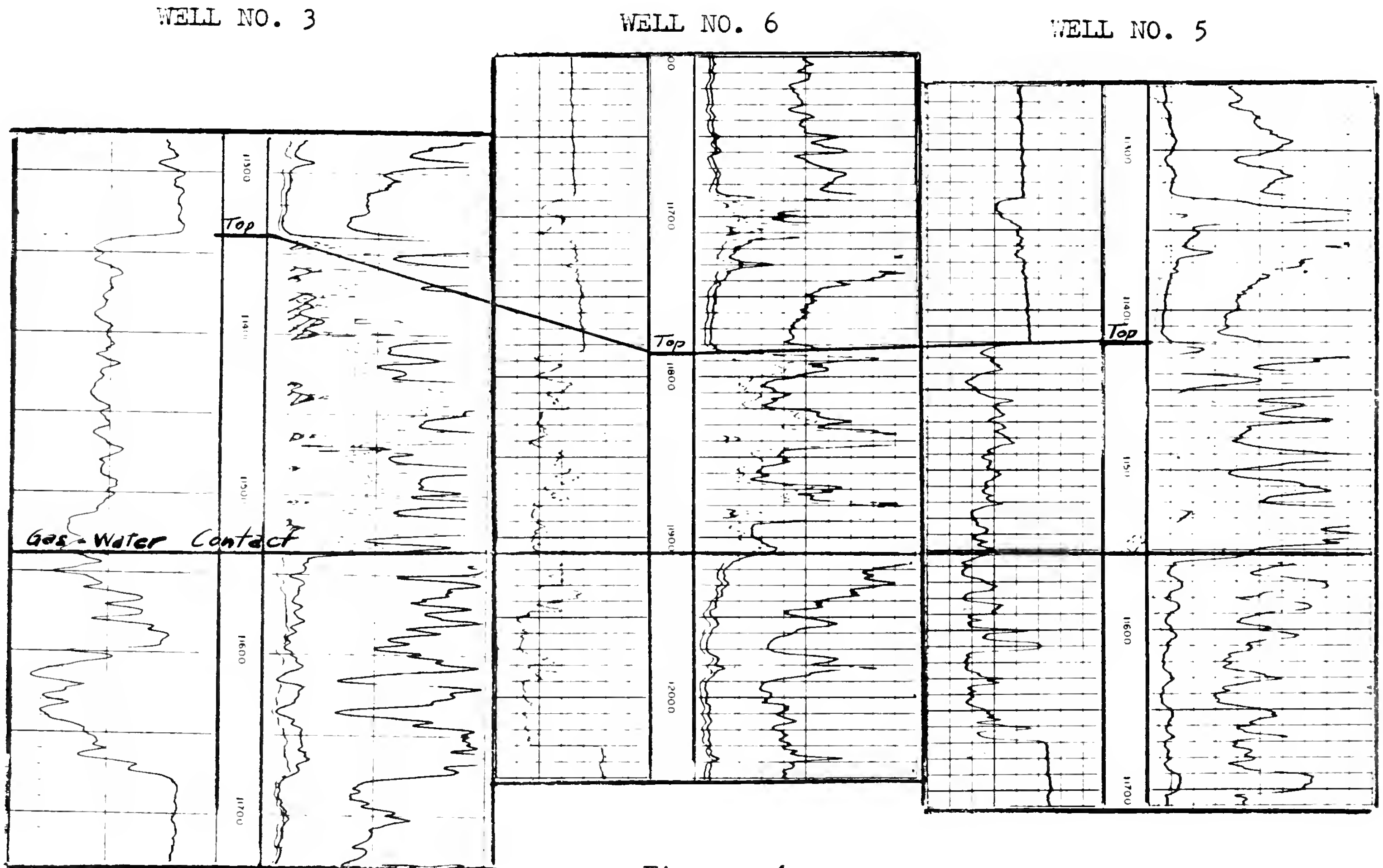


Figure 4

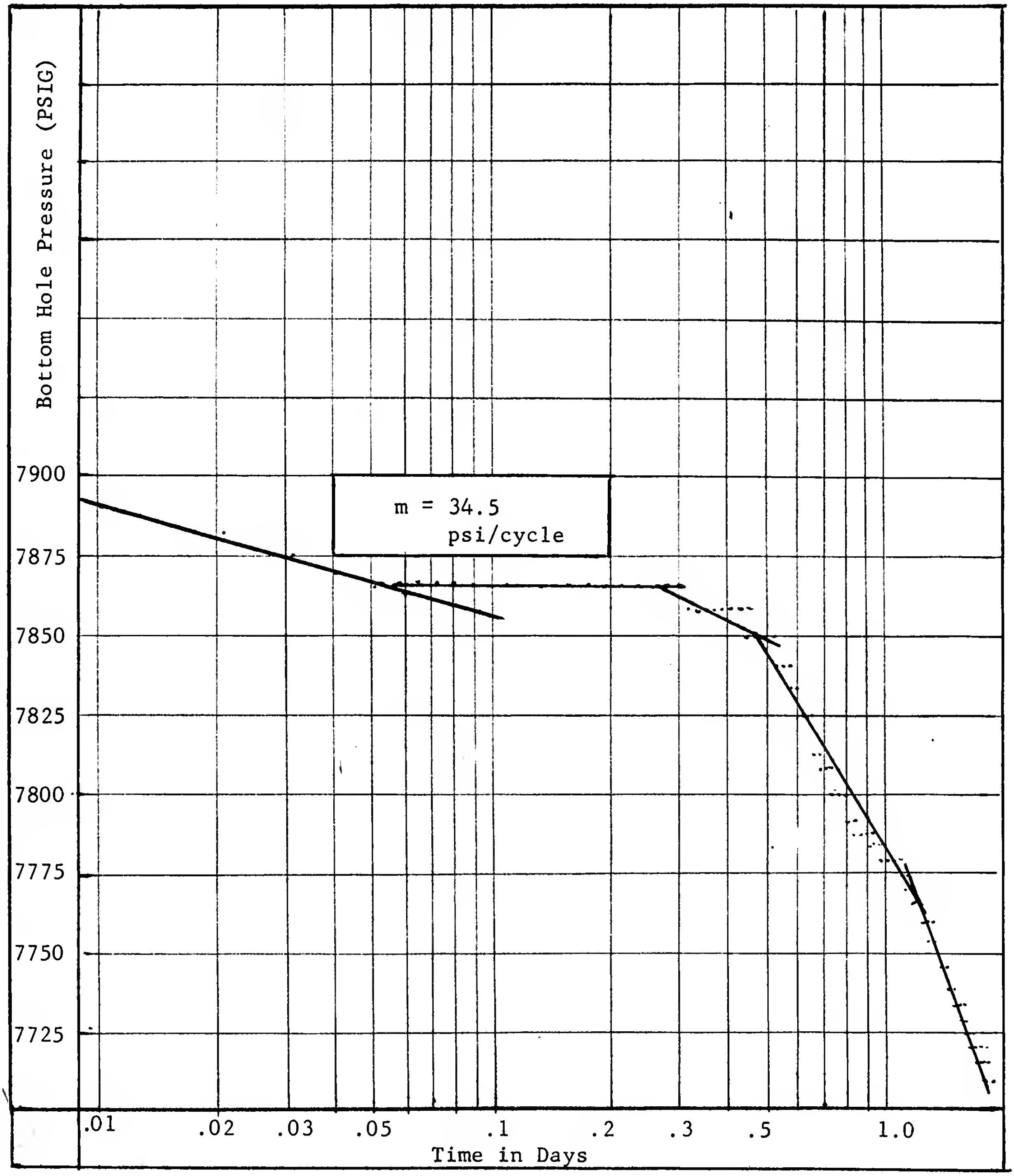
Side wall cores were available from one well. The porosity values obtained from the sidewall cores checked precisely the values obtained from the sonic logs and micrologs. The permeability, however, did not appear uniform, nor did these values check well against the effective permeability calculated from a pressure draw-down test or against permeability calculated from a resistivity gradient observed in some of the wells. The six values obtained from side-wall cores were 84, 134, 50, 512, 131 and 116 millidarcies. The effective permeability to gas obtained in the pressure draw-down test proved to be 50 millidarcies and this was the value used in the material balance calculations since the method of taking side-wall cores tends to result in fractured, non-representative samples of the reservoir. A plot of the data taken from the pressure draw-down test is shown in Figure 5.

For volumetric sweep-out calculations, 50 millidarcies was used for permeability while the effective thickness of pay was allowed to vary over the field. This gave a value of flow capacity for each point in the reservoir which was used in the sweep efficiency program.

Connate water saturation was found to be 20 per cent. This was an average value based on water saturation in the lower portion of the gas zone. Residual gas saturation to water is estimated to be 30 per cent. This is justified by the gas saturation near the top of the water column which, it

Pressure Drawdown Test

Figure 5



can be assumed, has encroached into the reservoir to some extent during a recent producing time.

Determination of net effective thickness in this formation was very difficult because of the shalyness of the sand and because of the meager geologic information. Only nine wells have penetrated the 2000 acres of estimated pay formation. The locations of the two faults--one thought to have a closure of about 100 feet in the northern extremity of the pool, the other with an estimated closure of about 120 feet in the south--are by no means exactly defined. An error of the position of the fault to the north of only a few feet would produce a substantial error in the estimated reserves because of the great thickness of pay adjacent to this fault. Calculation of reserves based on the volumetric method is presented in Table II. The east and west boundaries of the field are located at a gas-water contact which has shown little or no encroachment during the current gas production.

An isopach map produced from the nine control wells is presented as Figure 6.

A volumetric gas balance was made using the production data to date and bottom hole pressure tests taken in 1961 and 1963. A bottom hole pressure was obtained from the draw-down and build-up pressure test conducted in connection with this study. This gas balance was calculated on a Control Data Corporation 1604 high speed computer using a program developed by the Union Oil Company of California.

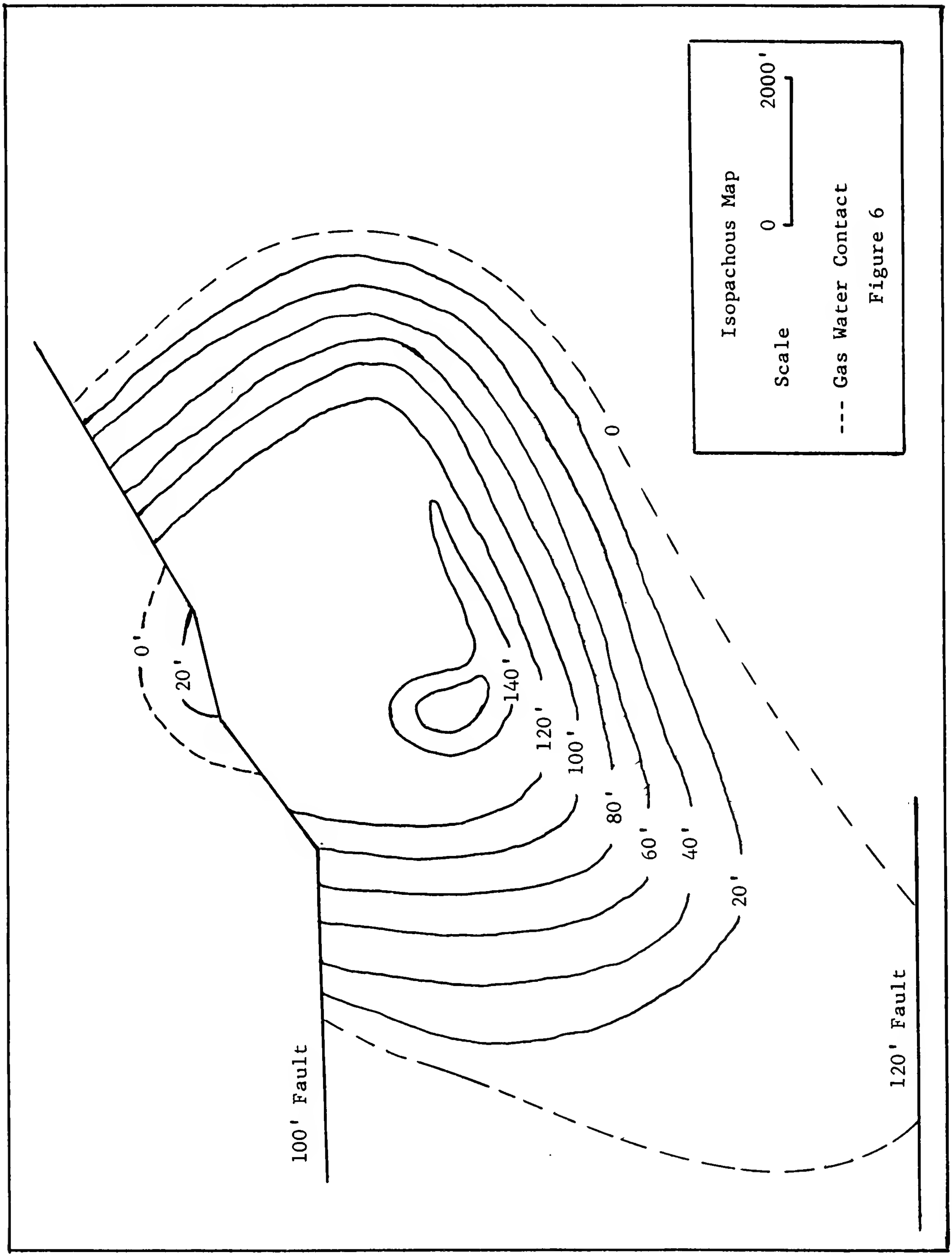

Isopachous Map
Scale 0 2000'
--- Gas Water Contact
0
0'
20'
140'
120'
100'
80'
60'
40'
20'
100' Fault
120' Fault

Figure 6

J. Donald Clark, Chief Reservoir Engineer for the Gulf Division of the Union Oil Company of California, has developed and applied or supervised the application of a very simple transient energy balance equation to numerous natural water drive gas reservoirs found in the Gulf Coast area.[12] A primary requirement of this equation is the derivation of the gas formation volume factor, B_g, to convert standard cubic feet of gas to reservoir barrels. This conversion for any particular reservoir is presented mathematically as follows:

1. $$B_g = \frac{15.025\ T_f}{520(5.61)} \times \frac{Z}{P} = .0051505\ T_f\ Z/P$$

Where:
15.025 is base pressure for Louisiana (psi)
520 is standard temperature ^{o}R
5.61 converts cubic feet to barrels
T is reservoir temperature, degrees Rankine
Z is gas deviation or compressibility factor
P is the reservoir pressure, psia
i as a subscript will denote initial or original conditions

The cumulative reservoir barrels of gas produced or withdrawn is equal to the cumulative reservoir barrels of gas expansion in the reservoir, or

2. $$G_{pw}\ B_g = G(B_g - B_{gi})$$

Where:
G_{pw} is cumulative standard cubic feet of wet gas produced
G is standard cubic feet of original gas in place

In the case of water drive reservoirs and water production the statement of the equation then becomes: (Cumulative Net

Reservoir Withdrawals) - (Cumulative Reservoir Expansion) = (Cumulative Water Influx), or

3. $(G_{pw} B_g + W_p) - G(B_g - B_{gi}) = W_e$

4. $(G_{pw} B_g + W_p) - G(B_g - B_{gi}) = A\Sigma\Delta PQ_r$

The water influx equation, $W_e = A\Sigma\Delta PQ_r$, is a simplified method of writing the equation presented by Hurst[5] in his paper entitled "Water Influx into a Reservoir and Its Application to the Equation of Volumetric Balance." Details of solving the water influx equation were presented by van Everdingen and Hurst.[6] The "A" is the water influx constant which encompasses conversion factors, porosity, radius of reservoir, effective reservoir thickness, effective compressibility of reservoir fluid, viscosity of reservoir fluid and fraction of reservoir perimeter exposed to water drive. The above parameters are constant for any particular reservoir and when used with the volumetric balance equation can be solved as an all encompassing constant for that particular reservoir.

The true simplification is in the manner of arriving at the value of $\Sigma\Delta PQ_r$ for various balancing periods.

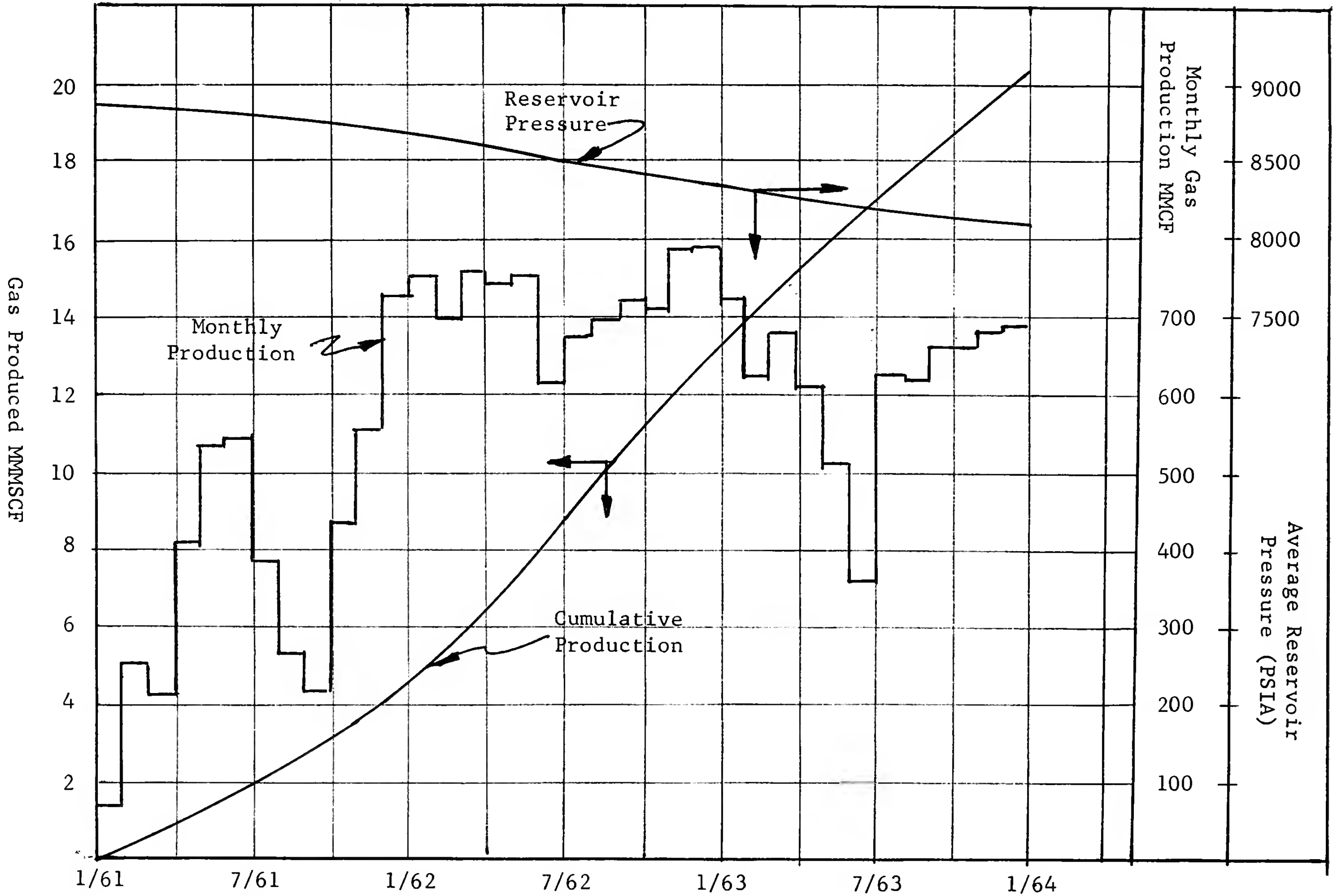
The dimensionless time equation, $t_D = KT/\phi\mu C_w r_b^2$ is derived from the hydraulic diffusivity factor, $\alpha^2 = K/\mu\phi C$ presented by Hurst[13] in 1933. The K, or permeability factor, actually is the one most difficult to measure since it is

effective permeability to water, which we seldom if ever obtain. This value could be found by running draw-down tests in salt water wells, but actually it can be estimated to a sufficient degree of accuracy. Viscosity of water can be obtained from various sources to a reasonable order of magnitude. Therefore, it becomes important only to establish an order of magnitude value of t_D, in order to extract reasonable values of the corresponding Q_r, the dimensionless water influx, from the tables.

Experience has shown that a proper time period should not exceed three months or approximately a 90-day producing period when attempting to strike a balance, especially if one plans to calculate future predictions. The constant "A" becomes an over-all correcting constant of transient flow, and allows us to solve very simply a satisfactory value of original hydrocarbons in-place and the total water influx at any time in the producing life of the reservoir.

Cumulative Production and Pressure History

Production from the reservoir is tabulated on a monthly rate and cumulated on a three-month basis. These data are broken down between oil, gas, condensate and water (both fresh and salt water). When rates of production have considerable variation, a monthly production rate should be plotted as shown on Figure 7. This plot is important in order to show the effect of rate on pressure when natural water drives exist.



Production History

Figure 7

Bottom hole pressure measurements are plotted versus time on the same graph as production rate. The length of shut-in time prior to each pressure measurement should be approximately equal and the individual pressures should have reasonably close values. If not, build-up or drawdown tests should be run to determine the cause of pressure variation. A pressure curve is then constructed through these evaluated pressure points. Experience and ingenuity are of tremendous value in constructing a reasonable curve. The production rate graph must be studied in order to prepare the most logical pressure-time curve. Pressure for uniform periods of production are taken directly from this graph.

Water Influx Data and Basic Calculations

The next step requires the gathering of basic information to approximate dimensionless time data and corresponding dimensionless rates.

$$t_D = \frac{KT(86,400)}{u\phi(0.5 \times 10^{-4})\ r_b^{\ 2}(930)}$$

Here geological data can be used to help determine the radius of the hydrocarbon reservoir. Only a close approximation is necessary. Compressibility of salt water can be found in the literature. Viscosity of salt water can be approximated by using chemical handbooks, available texts, and various publications; porosity is approximated from core analyses or logs

and permeability to water can be estimated from air permeability of cores analyzed.

Dimensionless time values are calculated for cumulative three-month periods. The corresponding Q_r values are taken from the table. Integration of the values for ΔP times Q_r over the cumulative time intervals yields the value which, when multiplied by the constant A, provides the cumulative water influx.

Gas Conversion to Reservoir Barrels

The vapor equivalent of the distillate and fresh water produced must be added to the amount of dry gas produced. The constant for converting liquid water to the vapor state is 7368.48 cubic feet per barrel. The distillate conversion factor was calculated from the hydrocarbon analysis of the separator liquid shown on page 89, Appendix II. This factor was found to be 768 standard cubic feet of vapor per barrel of distillate.

Method of Least Mean Squares for Striking an Energy Balance

The method of least mean squares is used for striking an energy balance for the natural water drive gas reservoir.

$$(G_{pw} + W_{ps}) - G(B_g - B_{gi}) = A(\Sigma\Delta PQ_r)$$

The two unknowns are G, the original wet gas in-place, and A, the water influx constant. The method herein presented

requires the solution for single values of A and G to meet all periods of past producing time. We, therefore, can arrive at two equations with two unknowns and place proportional weight to the length of production time:

$$[\Sigma(G_{pw} + W_{ps})(\Sigma\Delta PQ_r)] - G[(B_g - B_{gi})(\Sigma\Delta PQ_r)] = A[(\Sigma\Delta PQ_r)^2]$$

$$[\Sigma(G_{pw} + W_{ps})(B_g - B_{gi})] - G[(B_g - B_{gi})^2] = A[(\Sigma\Delta PQ_r)(B_g - B_{gi})]$$

These two equations can then be solved for A, the water influx constant, and G, the original wet gas in-place.

In order to check the validity of the values of A and G obtained by this method, multiply the LMSA value of A times $\Sigma\Delta PQ_r$ and solve for the apparent value of G. This is called "periodic check of balance for G assuming LMSA values of A as constant." The van Everdingen and Hurst solution to the diffusivity equation is here applied to single-phase fluid transient flow into a well bore for determination of the rate and volume of encroachment of water. The gas field is assumed to be embedded into an aquifer of large extent. In this instance, the reservoir is taken to be a large well, the radius of which is the equivalent field radius, and the aquifer is considered to be the reservoir from which fluid is withdrawn and water is expelled.[8]

The computer program, indicating method of computation, reservoir conditions, initial gas in place, and cumulative

water influx from past production data, is included as Appendix I.

Since the available geologic information is considered isufficient to describe the reservoir accurately enough for calculation of reserves, the results obtained from the volumetric gas balance were used for estimating original gas in place and water encroachment. These results were also the basis for the future performance prediction and economic analysis of alternate methods of exploitation. The original gas in place was found to be 606.9 billion cubic feet measured at standard conditions (15.025 psi at 60^{o}F). Water influx was found to be negligible.

C. <u>Reservoir Fluid Characteristics</u>

Samples of both the separator liquid and gas were obtained in March, 1964, and recombined in accordance with the measured gas-liquid ratio (stock-tank) of 17,150 SCF separator gas per bbl. stock tank liquid. It was difficult to obtain constant gas-oil ratios for the purpose of getting a representative sample and flowing at a constant rate for about three days was required before a steady GOR was achieved. Analysis of the recombined sample indicates a dew point pressure above the present bottom hole pressure. Retrograde condensation was taking place and two phase flow occurring near the well bore caused the fluctuating producing gas-liquid ratio. Reservoir temperature at time of sampling was 240 degrees farenheit.

Primary separation temperature was 125 degrees farenheit and primary separator pressure was 1020 psig. Dew point pressure was found to be 8260 psia and gas richness was 66.07 bbls. of stock tank liquid per million standard cubic feet of well stream effluent. Detailed results of the P-V-T investigation are included as Appendix II.

Samples of separator gas and separator liquid were analyzed by the conventional low temperature distillation method. The results are reported showing both the composition of each sample and the computed analysis of the well stream based on the gas-liquid ratio of the primary separator. The separator liquid production was calculated from the measured stock tank production by applying the determined shrinkage factor.

Following the compositional analyses, portions of the primary separator liquid and gas were physically recombined in their produced ratio in a variable volume, glass-windowed equilibrium cell. Determinations on this mixture were divided into the following two main categories:

I. Dew point pressure determination and pressure-volume relations on a constant weight of reservoir fluid at the reservoir temperature: The procedure consisted of establishing equilibrium between gas and liquid phases at a low pressure and measuring the volumes of liquid and gas in equilibrium at that pressure. The pressure was then raised by the injection of mercury into the cell and

phase equilibrium established again at the higher pressure. This procedure was repeated until all of the liquid phase had vaporized, at which point the saturation pressure was observed. The cell pressure was then raised above the dew point pressure in order to determine the supercompressibility characteristics of the single phase vapor. As a check on all readings and particularly to verify the dew point, the cell pressure was incrementally reduced, equilibrium established and volumetric readings made. Reported in Appendix II are the relative volume relations and specific volumes of the reservoir fluid over a wide range of pressures as well as deviation factors of the single phase vapor above the dew point. (Also reported in Appendix II are the dew point pressures resulting from recombinations at gas-liquid ratios above and below the ratio measured at the time of sampling.)

II. Compositions of the produced well stream and the amount of retrograde condensation resulting from a stepwise differential depletion: This procedure consisted of a series of constant composition expansions and constant volume displacements with each displacement being terminated at the original cell volume. The gas removed during the constant pressure displacement was charged to the low temperature fractional distillation equipment for analysis.

D. Conformance

The description of the simultaneous flow of fluids through porous media in terms of relative permeability and capillary pressure has been adequately discussed in the literature. For example, Muskat[9] in Chapter VII briefly discussed the dynamical effects associated with capillary phenomena. He also outlined the theory of potentiometric models and illustrated the application of the potentiometric model to cycling systems. Douglas, Peaceman, and Rachford,[10] presented a method for calculating multi-dimensional immiscible displacement based on a numerical solution of a finite difference analogue describing the displacement process. This technique insures that at any point in the sand, the flow of oil per unit area across the direction of flow can be represented by a vector $\vec{\mu}_o$ which is given by

$$\vec{\mu}_o = -K \frac{K_{ro}}{\mu_o} (\nabla p_o + \rho_o \, g \, \nabla h).$$

The operator, ∇, equals $\vec{i} \frac{\partial}{\partial x} + \vec{j} \frac{\partial}{\partial y}$; $\vec{i}$, $\vec{j}$ are unit vectors in the x and y directions, respectively; k is the local permeability, k_{ro} is the relative permeability to oil, μ_o the oil viscosity, p_o the pressure in the oil phase, ρ_o the oil density, and g the acceleration of gravity. Similarly,

$$\vec{u}_w = -k \frac{k_{rw}}{\mu_w} (\nabla p_w + \rho_w \, g \, \nabla h)$$

Fluid densities are assumed constant and oil and water

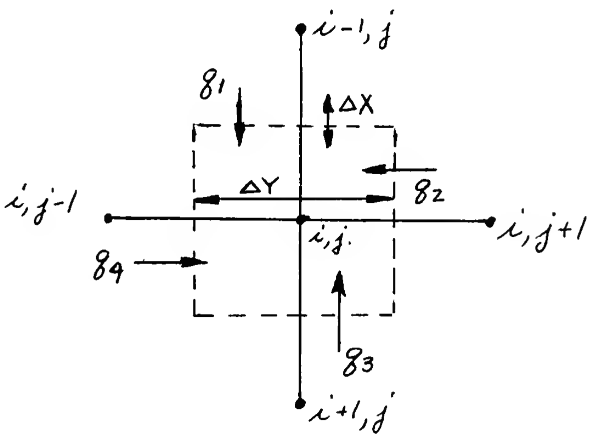
potentials are defined

$$\Phi_o = p_o + \rho_o gh$$

$$\Phi_w = p_w + \rho_w gh$$

The author proceeds to solve the problem by a system of difference equations.

In solving this reservoir a technique demonstrated by Dr. S. J. Pirson at The University of Texas is followed. In this method the reservoir is divided into a grid and each intersection of the grid is treated as a point (I, J) within the reservoir where Darcy's law may be applied. The flow across the grid between these points, q, is now analyzed. The rate of flow over a distince Δx across an area open to flow, Δy, can be determined by Darcy's law:



$$q_1 = 1.127 \frac{Kh}{\beta\mu_o} \Delta x [\frac{P_{(i-1,j)} - P_{(i,j)}}{\Delta y}]$$

In order to satisfy the continuity equation the vector sum of the flow in all four directions must equal zero unless

there is fluid withdrawal or fluid injection at the point

$$Q = q_1 + q_2 + q_3 + q_4$$

$$A = \frac{1.127}{\beta\mu_o}\,[K_{h_{av}}(P_{i-1,J}-P_{i,j})+K_{h_{av}}(P_{i,j+1}-P_{i,j})+K_{h_{av}}(P_{i+1,j}-P_{i,j}) +K_{h_{av}}(P_{i,j-1}-P_{i,j})]$$

It is seen that without injection or production from the point studied Q=0 and the $K_{h_{av}}$ is the average flow potential between adjacent points. This equation is now solved for $P_{i,j}$ and we find:

$$P_{i,j} = \frac{\frac{2Q\beta\mu_o}{1.127}+[K_{i+1,j}+K_{i,j})P_{i+1,j}+(K_{i-1,j}+K_{i,j})(P_{i-1,j})+ +(K_{i,j+1}+K_{i,j})(P_{i,j+1})+(K_{i,j-1}+K_{i,j})(P_{i,j-1})}{K_{i,j+1}+K_{i,j-1}+K_{i+1,j}+K_{i-1,j}+4K_{i,j}}$$

The boundary conditions are those restrictions on the limits of the connected region and the position and magnitude of the imposed flows or pressures. At the boundary of the permeable sand, the velocity of flow perpendicular to the boundary is zero, so it is sufficient to establish equal potentials across the boundary. Since $(\nabla\Phi) = 0$ across the boundary, no flow occurs. This same condition occurs at a fault boundary. As the water saturation increases near the water table, the relative permeability to water increases greatly while that to oil diminishes. By assigning these relatively high

values of flow potential in the equation aquifer pressure is maintained in the advancing flood front and movement of the front is regulated across this boundary.

In solving this potential equation for an oil reservoir, the term $-2\beta\mu_o/1.127$ is treated as a constant. However, since the flow equation depends on pressure, the constant for a gas field is augmented by a variable pressure term:

$$q = -1.127\,\frac{K}{\mu}\,\frac{dP}{dx} = \frac{(q_{sc})(P_{sc})(T)(z)}{(5.615)(T_{sc})(A)(P)}$$

For Oil For Gas

Volumetric sweep efficiency was investigated by this technique with the aid of a mathematical model which was run on the CDC 1604 high speed computer. This computer program is included as Appendix III. The program assumes steady-state flow at a point, and sequentially at each point in the reservoir in order that Darcy's flow equation may be applied. Using an alternating direction iteration procedure, the computer then reduces the total flow at each point in four directions to zero and by many iterations establishes each potential from the adjacent four potentials in order to achieve a balance. At each point selected on the model the quantity of flow into or out of the reservoir is assigned in the event a well is located at that point. The flow potential, or the product of effective permeability times the thickness of effective pay, is also assigned to each point. By applying Darcy's law in each of

four directions, by summation of these directional flow rates to zero, and by solving this equation for the potential at each point, a potential distribution map of the reservoir is produced. Isopotential contour lines are now drawn on a scale map of the reservoir. The primary criterion for equivalence between the model and the actual reservoir is the creation of geometrically similar potential fields which are determined only by the thickness, permeability, and boundary conditions. Flow lines were superimposed on the potential map and the method of squares utilized by Seba[11] is used to define the flow tubes through which a constant quantity of reservoir fluid would be expected to flow.

Flow lines of a fluid in a porous medium, as defined in Darcy's law, are everywhere orthogonal to the isopotential lines. The method of squares employs the fact that if a family of curves is constructed such that they are orthogonal to one member of another family of curves, then the second family of curves may be drawn orthogonal to the first. This is done by constructing them such that adjacent distances between the streamlines are equal to adjacent distances between the iso-potentials. A stream tube is a two-dimensional flow system defined as the area between two consecutive stream lines. Flow rate can be defined by the following:

$$Q = (h)\left(-\frac{k}{\mu}\right)(\Delta x)\left(\frac{\Delta\Phi}{\Delta s}\right)_{av}$$

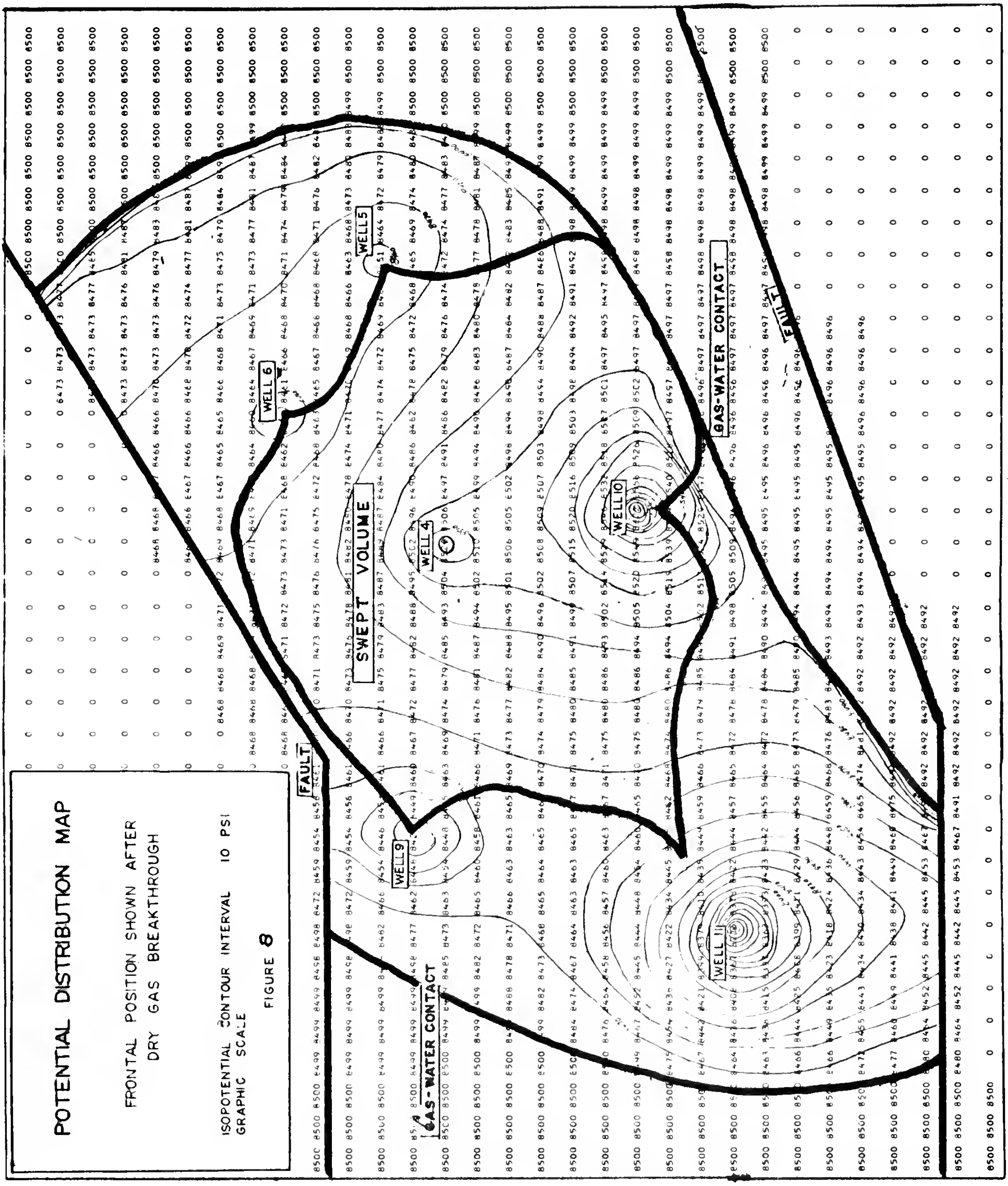
In any one square $\Delta x = \Delta s$ and Q is constant so:

$$\Delta t = (\text{constant}) \frac{\mu}{k\ h} \frac{(\Delta s)^2}{\Delta \Phi}$$

The increment of time can now be calculated for each of the squares within each flow tube so that the position of the front in each flow tube can be drawn at any selected time period. This procedure is repeated for various injection-production well combinations until the maximum volume of the reservoir is swept. Rearrangement of the well positions in the reservoir matrix is achieved simply by changing the quantity of flow into or out of that point in the reservoir. Sweep-out patterns were predicted with one, two and three injection wells and by using four producing wells. The locations of existing wells were used as much as possible but alternate new locations were also tried. The optimum combination was found to be two injection wells and four producing wells.

Wells marked "Well 4" and "Well 10" on Figure 8 are to be recompleted as injection wells. Two new wells are required at the locations marked "Well 5" and "Well 11." An existing well at location "Well 9" is to be recompleted in the pay zone studied since it is now producing from a deeper zone. "Well 6" is producing from this formation and will continue to be used for this project.

A machine print-out of the potentials has been reduced to a map shown in Figure 8 picturing the isopotential contour lines and on which the frontal position has been drawn at one



POTENTIAL DISTRIBUTION MAP

FRONTAL POSITION SHOWN AFTER DRY GAS BREAKTHROUGH

ISOPOTENTIAL CONTOUR INTERVAL 10 PSI
GRAPHIC SCALE

FIGURE 8

time just after breakthrough of the injected residue gas. The volume of the reservoir swept at this breakthrough time was found to be 65%.

The ability of the dry absorber gas to vaporize the condensate in the sand was determined by pressure-volume-temperature tests run on a recombined sample of the gas. Results of these tests are given in Appendix II. The overall displacement efficiency of the residue gas was found to be 92%.

The effect of bypassing on a local scale, due to permeability variations, was analyzed as demonstrated by Standing,[7] by arriving at a permeability variation for the sand. Although insufficient data are available to establish firmly the permeability variations throughout the reservoir, a variation .30 was assigned. This value gives a sweep efficiency at breakthrough of 87%.

Using the product of these three conformance factors, the overall volume of the reservoir swept out at breakthrough was 51%, with the dry gas cut after breakthrough increasing in the manner calculated by Standing[7] in the paper mentioned before. Cycling of gas was discontinued when proportion of reservoir gas produced was reduced to 67% by dilution with cycled residue gas, due to the cycling economic limit having been reached.

CHAPTER IV

PERFORMANCE PREDICTION

A. Pressure Depletion Method

Past production has averaged 25 million standard cubic feet per day from the reservoir studied. Until this time no firm estimate had been made on the reserves nor had any analysis been made to predict the future performance and probable life of the reservoir. From the past production figures the initial gas in place was estimated and the pressure decline and water influx was analyzed. From these data it is possible to predict the future performance of the field. This was done through the use of the computer program included in Appendix IV.

Because of insufficient pressure decline and the lack of back pressure data it is not possible to predict deliverability deterioration with declining pressure. It is anticipated that as liquid saturation around the well bore increases with static pressure reduction and with more severe pressure drawdown, deterioration of deliverability will result. For the purposes of this study, in absence of definitive data, the rate of production of dry gas was assumed to remain constant and at the current rate. The water influx constant obtained from the volumetric gas balance program was used to obtain future performance prediction as well as the calculated quantity of

initial gas in place and the adjusted pressure decline figures.

The amount of condensate produced, by year, was calculated from the P-V-T data obtained in the material balance calculations performed on the recombined gas sample placed in the equilibrium test cell. In this cell the pressure was depleted by removing successively small quantities of gas from the cell. Thermodynamic equilibrium was established, material balance calculations were made, and retrograde liquid volumes and the gravity of the effluent gas were measured at each step. The gas removed in each depletion step was charged to the low temperature distillation equipment for analysis. The produced volumes of reservoir gas, the determined compositions, computed gallons per thousand standard cubic feet (GPM) content and respective deviation factors are presented in Appendix II. The volume of retrograde liquid resulting from this depletion study is also shown in Appendix II, both in terms of barrels of reservoir liquid and per cent of hydrocarbon pore space. Shown also are the compositions of the gas and liquid remaining in the reservoir after depletion to abandonment pressure. The amount of condensate calculated to be produced with the well stream at each pressure decrement in the future prediction was tabulated. The value of gas sold under the terms of the present contract is $.20 per MCF and condensate is sold for $2.95 per barrel. These prices are assumed

to be firm for future sales. Operating costs are averaging \$.00423 per MCF produced and product transportation charges for the condensate sold are averaging \$.1375 per barrel. Application of these values to depletion of the reservoir over a fifty-year period with net income discounted at 6% results in a present worth of \$38,749,249. It is seen that in this case of pressure depletion to 1500 psi only 73.51 per cent of the initial gas in place was produced. Since the gas is to be delivered to a pipeline at a pressure in excess of 1000 psi, further recovery would require recompression to the sales gas line. This secondary recovery process was not considered in this study because the value of gas recovered 50-odd years hence is not relevant for a study of possible investments now.

It is significant to note that the condensate recovered by pressure depletion amounts to 15.4 million barrels which is scarcely 38% of the more than 40 million barrels of recoverable oil initially in place.

B. Pressure Maintenance through Gas Cycling

A program of gas cycling was considered wherein gas sales from the reservoir would be terminated and all gas produced from the reservoir, together with enough make-up gas to allow for compression and other gas losses, would be reinjected after extraction of all condensable heavier hydrocarbons. As determined by the sweep efficiency model studies, two wells

should be recompleted as injection wells and four wells would be used as producing wells as shown in Figure 8. Since the installation is located off shore the wet gas would be processed in low temperature units on platforms near the producing wells. The residue gas would be piped from the separators to the injection platform which would be located at one of the injection wells. Double extra heavy pipe would be necessary to carry the compressed injection gas to the other injection wells since injection pressures in excess of 8000 psi will be encountered.

Condensate produced in the separator units would be metered and then reinjected into the gas sales line of the gas company where it would be transported with other wet gas to the on-shore extraction plant for processing.

Under pressure maintenance it is assumed that the reservoir will continue to produce a gas of the richness measured in the most recent flow tests until breakthrough of the injected dry gas into the first producing well. From this point in time the produced gas would decline in richness in direct proportion to the residue gas cut produced. When the amount of injected dry gas obtained through the production wells reached 1/3 of the total gas processed it was found uneconomical to continue gas injection. Injection would be discontinued and gas sales would begin to deplete the reservoir to about 1300 psi or until compression was necessary to charge the sales

gas line. Production past this point was not considered part of this study.

It was assumed that the wet gas produced would be in equilibrium at the pressure and temperature produced in the same proportion as that indicated by the equilibrium cell tests. In the equilibrium cell the recombined gas sample was allowed to expand at constant composition with each pressure decrement and then gas was extracted at constant pressure, thus simulating reservoir withdrawals. The material balance calculations resulting from these tests are believed to depict more realistically the actual reservoir performance than calculation of the material balance by means of equilibrium constants.

Based on a permeability variation of .30 as defined by Standing[7] the dry gas cut at the producing wells was estimated from the first breakthrough at a producing well until the economic limit of injection was reached.

Extraneous gas is available in excess of present available market in a reservoir below the zone studied and consequently at a higher pressure. This gas would be used as make up gas in the pressure maintenance case to compensate for losses due to fuel consumption and condensate production.

After the economic limit is reached it is assumed that gas sales will begin again at the present rate and that prevailing prices would still be applicable.

Since the field is just beginning to enter the retrograde condensation phase considerably more condensate will be

produced by pressure maintenance if this procedure can be started at once. The greater the decline in pressure before injection commences the greater will be the losses in the reservoir and the higher will be the value of extraneous gas injected.

Because of the loss in gas sales during the period of pressure maintenance this procedure does not appear economically attractive unless market availability for present gas sales can be filled from another source of gas. The ultimate recovery of condensate through pressure maintenance is excellent from a conservation point of view since over 90% of the available condensable hydrocarbon is expected to be recovered through the combination of dry gas injection to maintain pressure, to be followed by reservoir blowdown to depletion.

C. Cycling with Pressure Depletion

Return to the reservoir of available gas from the high pressure separator constitutes normal cycling. Since a net voidage situation exists as a result of shrinkage and fuel losses from the produced gas, normal cycling results in only partial pressure maintenance. However, the pressure reduction would be little more than 40% during the full economic cycling life.

As in the case studied for full pressure maintenance, two wells would be used for injection of residue gas and four wells would be used for production of the wet gas effluent as indicated in the sweep model study. (See Figure 8.)

In this analysis gas sales are continued at the present rate which is dictated by the available gas market. Provision is made for compressors adequate to compress 40 million standard cubic feet of residue gas per day for injection. All wet gas produced is processed through the low temperature units on offshore platforms. The sales gas and all the condensate produced is charged to the sales gas line provided by the gas company.

The amount of condensate produced will be governed by the equilibrium saturation at the prevailing producing bottom hole pressure until breakthrough of detectable dry gas. From this point onward the increasing dry gas cut will be governed by the permeability stratification as well as by the areal sweep pattern. As the cycling reaches its economic limit, the compressors will be shut down and sales gas production will continue to deplete the field. Production below 1300 psi was not considered in this study, since compression would be required to charge the sales gas line which is maintained in excess of 1000 psi.

It is predicted that normal cycling to .67 reservoir-gas cut followed by pressure blowdown will result in the recovery of 26,876,000 stock tank barrels of condensate or 67% of the available condensable hydrocarbons. Although the total amount of condensate produced through normal cycling is considerably less than for the pressure maintenance case, the

present worth of the income from early gas sales tended to make normal cycling more attractive economically. The advantage of normal gas cycling, then, is continued income from the available market for gas while producing more condensate than would have been produced through normal pressure depletion and by producing this condensate earlier in the life of the field and in excess of available market for residue gas.

CHAPTER V

CONCLUSIONS

A. Comparison of Ultimate Recoveries

In a condensate reservoir, income is derived from the sales, not only of the residual gas produced, but also the liquids produced from the reservoir gas by mechanical separation or other type of plant processing. The ultimate quantity of these fluids produced is of importance as well as the rate of this production.

The original gas in place is the same in any case. The ultimate produced quantity of this gas, however, is governed by the amount of fuel required in its production, or in the production of its condensate, and also by the reservoir pressure at abandonment. The time at which this gas will be produced is dependent, of course, on the rate at which it is produced which in turn is dependent on the available marketing possibilities. In each of the alternatives studied the ultimate quantity of gas recovered was essentially the same, while the timing of the recovery of the gas was dependent on the method of field exploitation.

The amount of condensate recovered is dependent on the pressure within the reservoir while being produced, since the retrograde properties of the reservoir fluid causes much of the heavier liquid hydrocarbon to remain within the reservoir

rock. By producing the reservoir at a pressure at which retrograde condensation will not occur or where it approaches some minimum value the quantity of condensate ultimately recovered is increased.

The rate at which condensate is produced is dependent upon the rate of gas production unless some extraordinary means is provided to extract the condensate in advance of gas sales. This is the case in most gas reservoirs since pressure depletion without gas cycling is generally the method used for recovery.

By cycling a part or all of the gas produced back into the reservoir not only can the condensate be extracted in advance of a gas market, but also the pressure can be maintained at a level where little or no retrograde loss will occur in the reservoir. In the pressure maintenance case the rate of condensate recovery is limited only by the size of compressor plant installed. In the normal cycling case the rate is determined by the sum of the available gas market coupled with the capacity of the compressors. Under pressure maintenance essentially all, 95%, of the condensate is ultimately recovered and through normal cycling 67% is recovered. When compared with recovery of condensate by pressure depletion of only 38% of the liquid, it is apparent that cycling is an important conservation measure.

A comparison of ultimate recovery for both gas and condensate is presented in Table I. A plot of predicted

cumulative condensate recovery versus time is presented as Figure 9.

B. Economic Analysis of Alternatives

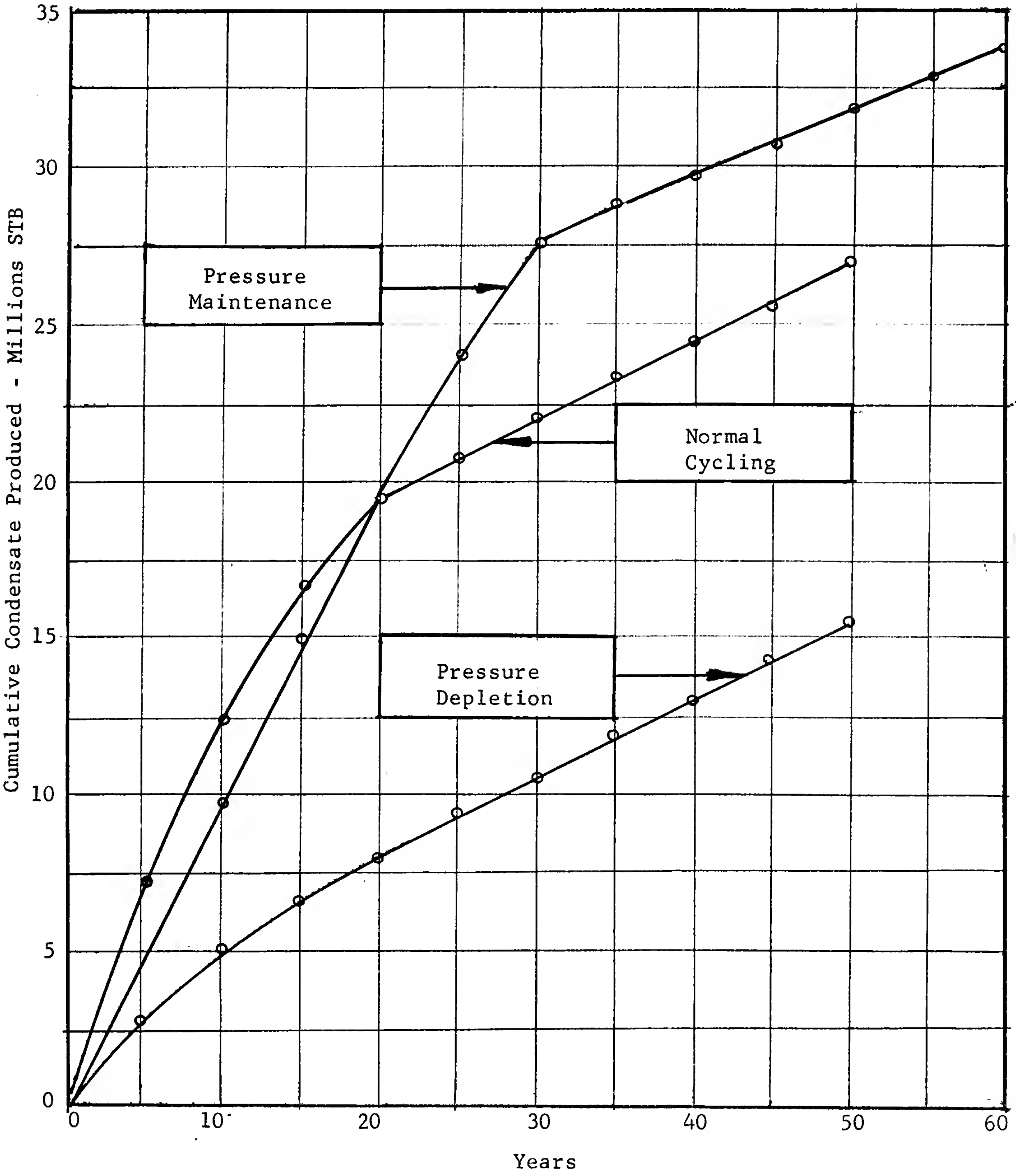
Since the quantity of gas ultimately to be recovered is essentially the same by any method of exploitation, the only factor in gas production contributing to its present value, and hence important in an economic analysis, is the time at which this gas is produced. In order to obtain maximum value from this valuable resource, the gas should be produced in as great a quantity as can be marketed. In the case of pressure depletion and in the case for normal gas cycling, gas was sold at the maximum rate limited only by the market obtainable. In the case for pressure maintenance the sale of gas was postponed for thirty years and this fact contributed to the reduced present worth for this alternative.

Through pressure depletion 15,430,000 barrels of condensate would be produced which is 38.6 per cent of the liquid originally in the reservoir. Should cycling while continuing to market gas be adopted, 26,876,000 million barrels of condensate would be recovered. This is possible because increased condensate recovery while the reservoir pressure is still relatively high is made possible by the larger quantity of gas passing through the separators. Under the pressure maintenance program nearly all of the condensate, 38,090,000 barrels, can

Figure 9

Predicated Cumulative Condensate

Recovery vs Time



be expected to be recovered, since the retrograde condensation caused by drop in reservoir pressure will not occur.

A summary of the economic comparison of the three alternative studies is included as Table I. From this summary it can be seen that the normal cycling program has the greatest present worth to an investor. This results from maximizing the value of gas in place by making use of the available market and combining this income with increased condensate recovery through retrieval at elevated pressure. Earlier retrieval of this condensate further contributes to its present net worth.

Pressure maintnenace results in the maximum ultimate recovery of both the residue gas and the condensate. The postponement of gas sales until the economic limit of the cycling of the injection gas is reached, however, makes this procedure unattractive economically. Only if there was no market for gas at the present time, or if the available market could be satisfied by gas from another pool, could investment in pressure maintenance prove feasible. In this event, pressure maintenance would be the logical choice since the gas would have no present value for any of the alternatives and extraneous gas injection to maintain pressure would result in valuable recovery of condensate not otherwise obtainable.

The pressure depletion of the reservoir proves to be the least attractive program both from the conservationist viewpoint of quantity of hydrocarbons recovered and from the investor's

TABLE I

ECONOMIC SUMMARY

	Pressure Depletion	Pressure Maintenance	Normal Cycling
Project Life	50 years	80 years	50 years
Condensate Production, M-Barrels	15,430	38,090	26,876
Total Sales Gas Production, MMMSCF	492.7	492.7	492.7
Ultimate Condensate Recovery, % of original	38.6	95.0	67.2
Gross Working Interest Income, M-$	114,934	175,367	142,860
Operating Expense, M-$	4,100	16,367	11,760
Operating Income, M-$	110,834	159,000	131,100
Capital Investment, M-$	---	4,000	5,000
Total Cash Flow, M-$	110,834	155,000	126,100
Present Value, M-$	38,750	30,000	47,784

approach to maximizing profit from the invested dollar. From market data available pertaining to recovery from this field, some steps toward increasing condensate recovery by gas cycling should be taken at the earliest possible time. Since the reservoir is entering the retrograde phase now, time is of the essence if losses from this phenomenon are to be prevented.

Graphs of the Annual and Cumulative Cash Plans versus time are shown for the three alternatives studied in Figures 10, 11, and 12.

Capital expenditures required for gas cycling are given in Table VIII, page 72.

Figure 10

Annual and Cumulative Cash Flow

Straight Pressure Depletion

at Current Rate

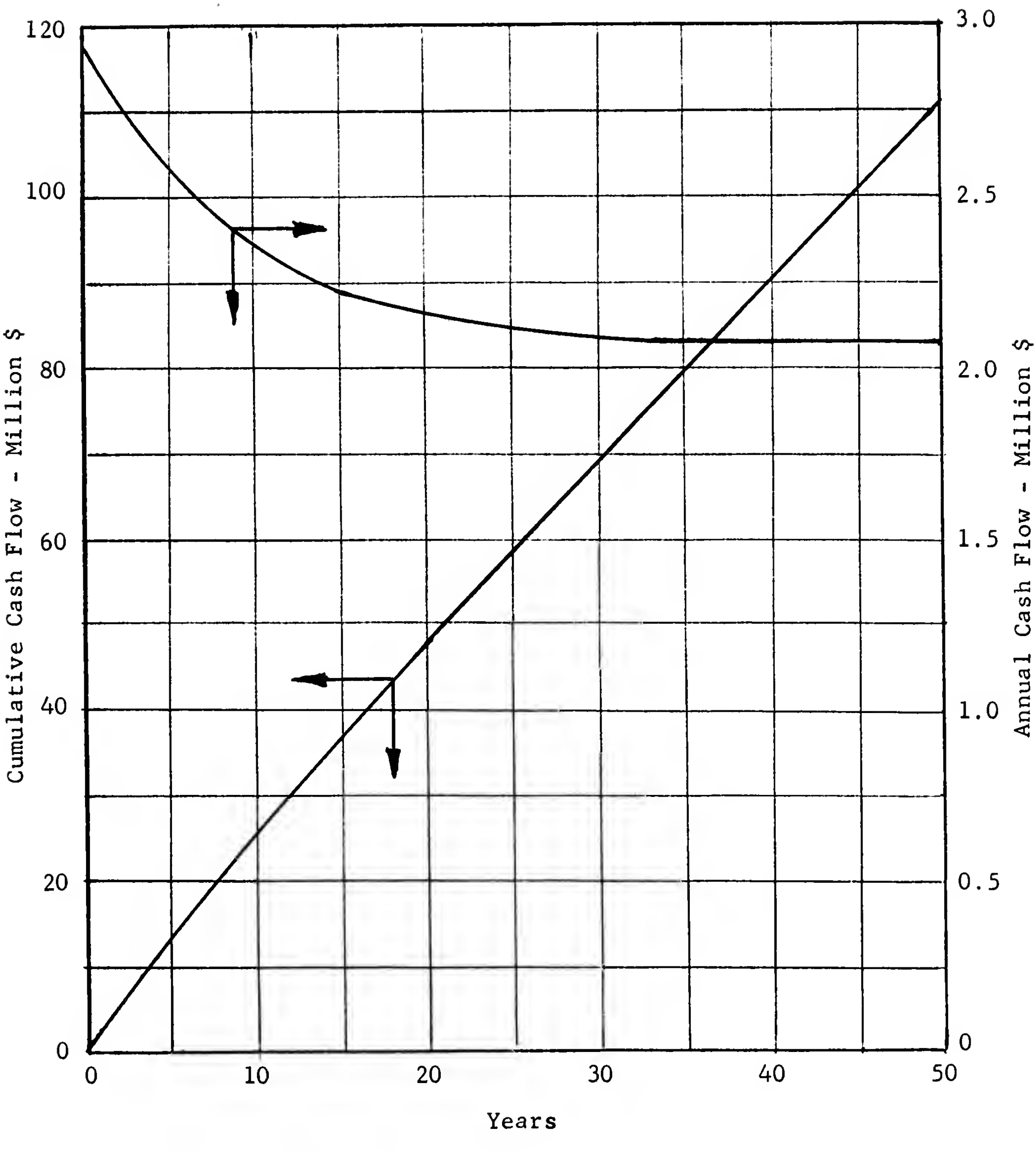


Figure 11

Annual and Cumulative Cash Flow

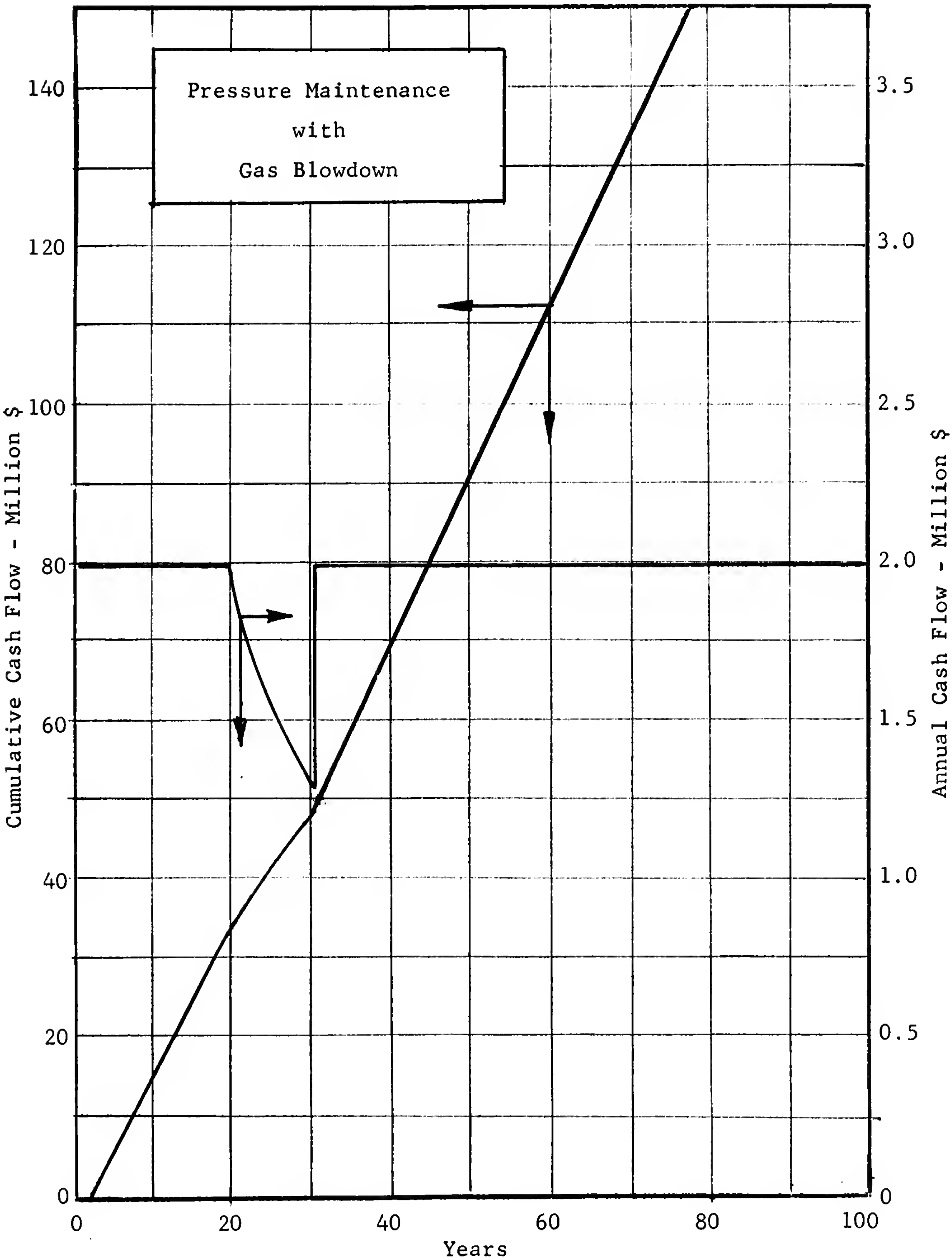
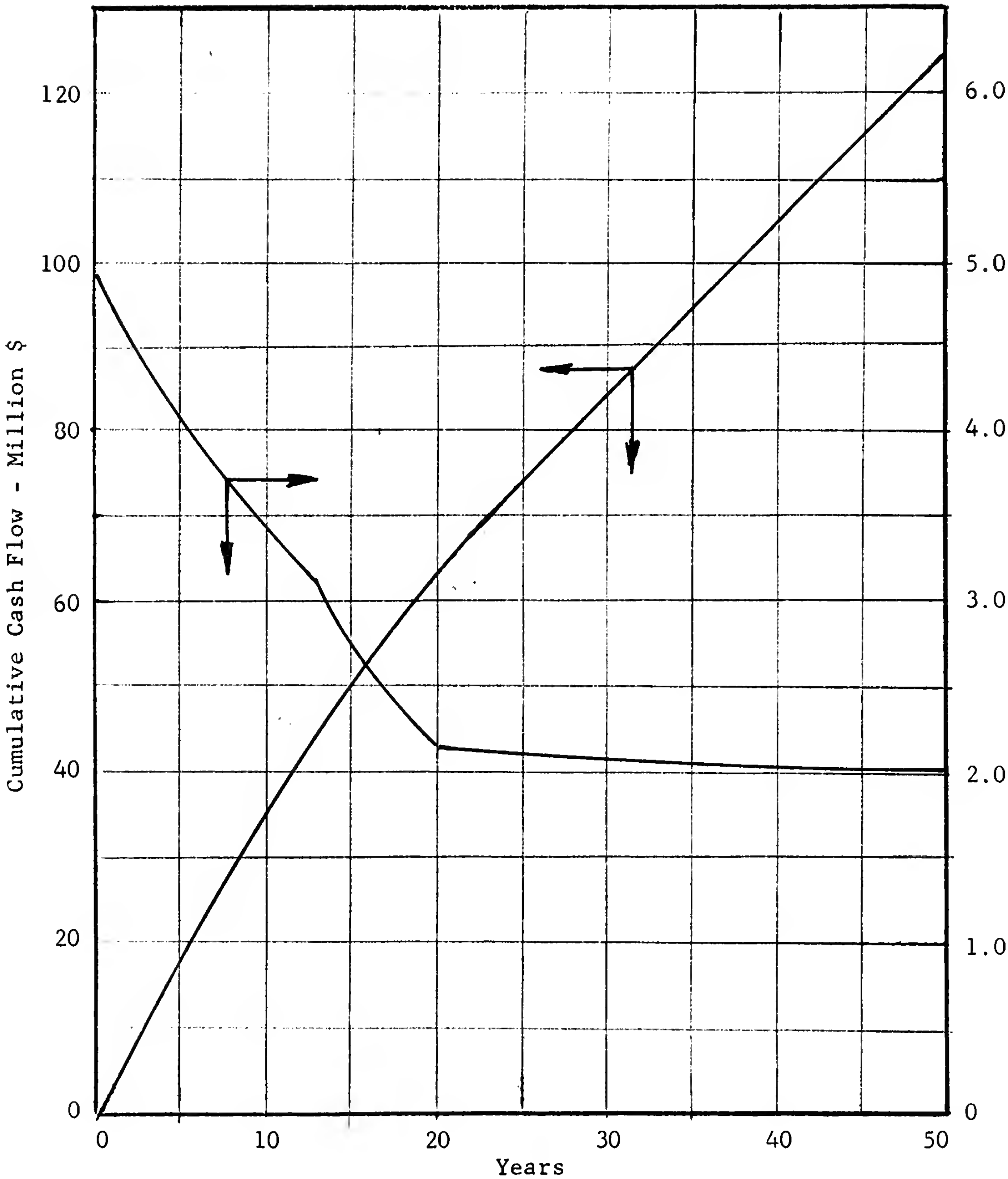


Figure 12

Annual and Cumulative Cash Flow

Normal Gas Cycling with

Pressure Depletion



CHAPTER VI

RECOMMENDATIONS

Based on the conclusions determined by the investigation of the supplementary condensate recovery programs studied, it is recommended that the following course of action be undertaken by the field operators:

1. Organize an active operators committee for the express purpose of working toward the unitization of the reservoir.

2. Charge the technical subcommittee with the responsibility of a detailed engineering design for a successful normal cycling program.

3. Charge the appropriate subcommittee with the preparation of unitization and operating agreements.

4. Dedicate the manpower necessary to complete the engineering design at the earliest possible time to gain the advantage of the highest reservoir pressure attainable during recovery.

5. Commence normal cycling of the residue gas to increase condensate recovery at the earliest practicable date.

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DEFINITION OF TERMS

We	Water influx
C_{e_w}	Effective water compressibility (taking into account rock expansion into pore space because of geostatic compression of the reservoir rock
R_b	Equivalent field radius
G_{pw}	Cumulative wet gas produced (SCF)
G	Initial gas in place (SCF)
K	Permeability in darcies
ϕ	Porosity
μ_w	Viscosity of water
h_e	Effective pay thickness
e_v	van Everdingen and Hurst water influx constant
Q_{sc}	Flow rate for well tests
T_f	Temperature of formation (degrees Rankine)
μ_g	Viscosity of gas
m	Slope of drawdown curve (psi/cycle)
P	Reservoir pressure (psia)
B_g	Gas formation volume factor
Z	Gas deviation or compressibility factor
i	Subscript denoting initial value
ΔP	Reservoir pressure decrement
Q_r	Infinite aquifer values of dimensionless water influx for values of dimensionless time, t_D
t_D	Dimensionless time
A	Water influx constant
T	Real time
V_B	Bulk volume of the reservoir

TABLE II

CALCULATION OF INITIAL GAS IN PLACE BY VOLUMETRIC METHOD

Area	Planimeter (sq. in.)	Area (acres)	Ratio of Areas	Interval ft.	Equation	ΔV acre-ft.
A_0	21.60	1983.46				
A_1	15.15	1391.18	.70	20	Trap	33746
A_2	12.65	1161.61	.83	20	Trap	25528
A_3	10.23	939.39	.81	20	Trap	21010
A_4	8.44	775.02	.83	20	Trap	17144
A_5	6.80	624.42	.80	20	Trap	13994
A_6	5.35	491.27	.79	20	Trap	11157
A_7	.52	47.75	.096	20	Pyr.	4613
A_8	.14	12.86	.27	20	Pyr.	569
A_9	0	0	.00	15	Pyr.	64

$1 \text{ in}^2 = 91.827$ acres

Pyramidal formula: $\Delta V_B = \frac{h}{3}(A_n + A_{n+1} + \sqrt{A_n A_{n+1}}$

Trapezoidal formula: $\Delta V_B = \frac{h}{2}(A_n + A_{n+1})$

$V_B = 127{,}825$ acre-ft

$G = 7758 \times V_B \times \phi \times (1 - S_w) \times B_G$

$G = 7758(.28)(.8)(1862.2)(127{,}825) = 415 \times 10^9$ SCF

$\phi = .28$

$S_w = .20$

$B_g = .000537$ bbl/cu.ft. or 1862.2 SCF/bbl

Calculation of Flow Capacity

$$K_{h_e} = \frac{(0.819)(Q_{sc})(T)(Z)(\mu_g)}{(m)(P)}$$

TABLE II--Continued

$$K_{h_e} = \frac{(0.819)(9400)(700)(1.327)(.034)}{(34.5)(8000)} = .880 \text{ darcy-ft.}$$

$$K = \frac{.880}{17.5} = .050 \text{ darcies}$$

TABLE III

MONTHLY PAST PRODUCTION

	MCF GAS	BBLS DISTILLATE	BBLS WATER
1/61	76,227	3,733	8
2/61	250,783	15,098	368
3/61	211,234	16,196	399
4/61	409,576	27,841	130
5/61	538,319	42,100	86
6/61	543,289	42,403	282
7/61	388,364	28,872	143
8/61	263,335	18,530	35
9/61	217,357	15,133	84
10/61	433,201	30,583	138
11/61	553,913	39,992	300
12/61	729,040	54,549	217
1961	4,614,638	335,030	2,190
1/62	750,948	54,465	279
2/62	696,327	52,138	112
3/62	758,887	57,031	465
4/62	741,272	56,523	420
5/62	756,234	55,536	434
6/62	618,763	45,731	322
7/62	675,888	52,441	319
8/62	696,371	47,460	465
9/62	721,975	49,439	348
10/62	712,711	49,682	496
11/62	787,513	60,470	420
12/62	788,886	60,725	527
1962	8,705,775	641,641	4,607
1/63	723,591	61,729	465
2/63	626,203	49,738	28
3/63	697,915	51,312	31
4/63	610,953	49,704	300
5/63	514,623	40,434	243
6/63	358,040	31,177	108
7/63	625,669	47,156	280
8/63	620,714	49,127	424
9/63	665,982	45,531	---
10/63	666,848	46,491	---
11/63	686,364	43,249	---
12/63	691,439	49,899	---
1963	7,470,341	565,547	1,879
TOTAL	20,790,754	1,542,218	8,676

TABLE IV

PRESSURE DRAWDOWN-BUILDUP TEST

Offshore, Louisiana

Pressure Drawdown				
Date	Time	Elapsed Time Days	Bottom Hole Press. Psig.	Remarks
3-24-64	9:00 A.M.			Wound 72 hour clock
	9:10			Engaged clock & stylus
	9:15			Pressured lubricator
	9:35		8236	Bomb placed at 11,745'
	10:45	0	8236	Started opening well
	10:52-1/2	.0052	7943	Well flowing 9400 MCF
	11:00	.0104	7892	
	11:07-1/2	.0156	7884	
	11:15	.0208	7884	
	11:30	.0313	7876	
	11:45	.0417	7876	
	12:00 noon	.0521	7867	
	12:30 P.M.	.0729	7867	
	1:00	.0938	7859	
	1:30	.1146	7867	
	2:00	.1354	7867	
	2:30	.1562	7867	
	3:00	.1771	7867	
	3:30	.1979	7867	
	4:00	.2187	7867	
	4:30	.2396	7867	
	5:00	.2604	7867	
	5:30	.2812	7867	
	6:00	.3021	7867	
	6:30	.3229	7859	
	7:00	.3437	7859	
	7:30	.3646	7859	
	8:00	.3854	7859	
	8:30	.4062	7859	
	9:00	.4271	7859	
	9:30	.4479	7859	
	10:00	.4687	7851	
	10:30	.4896	7851	
	11:00	.5104	7851	
	11:30	.5312	7851	
	12:00 midnt.	.5521	7842	

TABLE IV--Continued

Pressure Drawdown				
Date	Time	Elapsed Time Days	Bottom Hole Press. Psig.	Remarks
3-25-64	12:30 A.M.	.5729	7842	
	1:00	.5937	7843	
	1:30	.6146	7825	
	2:00	.6354	7825	
	2:30	.6562	7817	
	3:00	.6771	7813	
	3:30	.6979	7809	
	4:00	.7187	7809	
	4:30	.7396	7800	
	5:00	.7604	7800	
	5:30	.7812	7800	
	6:00	.8021	7792	
	6:30	.8229	7792	
	7:00	.8437	7792	
	7:30	.8646	7788	
	8:00	.8854	7788	
	8:30	.9062	7788	
	9:00	.9271	7784	
	9:30	.9479	7784	
	10:00	.9687	7784	
	10:30	.9896	7784	
	11:00	1.0100	7780	
	11:30	1.0310	7780	
	12:00 noon	1.0520	7780	
	12:30 P.M.	1.0730	7780	
	1:00	1.0940	7776	
	1:30	1.1150	7776	
	2:00	1.1350	7776	
	2:30	1.1560	7771	
	3:00	1.1770	7771	
	3:30	1.1980	7767	
	4:00	1.2190	7767	
	4:30	1.2400	7767	
	5:00	1.2600	7763	
	5:30	1.2810	7759	
	6:00	1.3020	7759	
	6:30	1.3230	7755	
	7:00	1.3440	7755	
	7:30	1.3650	7751	
	8:00	1.3850	7751	
	8:30	1.4060	7746	

TABLE IV--Continued

Pressure Drawdown				
Date	Time	Elapsed Time Days	Bottom Hole Press. Psig.	Remarks
3-25-64	9:00 P.M.	1.4270	7746	
(Cont.)	9:30	1.4480	7742	
	10:00	1.4690	7742	
	10:30	1.4900	7738	
	11:00	1.5100	7738	
	11:30	1.5310	7734	
	12:00 midnt.	1.5520	7734	
3-26-64	12:30 A.M.	1.5730	7734	
	1:00	1.5940	7734	
	1:30	1.6150	7734	
	2:00	1.6350	7734	
	2:30	1.6560	7730	
	3:00	1.6770	7730	
	3:30	1.6980	7725	
	4:00	1.7190	7725	
	4:30	1.7400	7725	
	5:00	1.7600	7721	
	5:30	1.7810	7721	
	6:00	1.8020	7717	
	6:30	1.8230	7717	
	7:30	1.8650	7717	
	8:30	1.9060	7709	
	9:30	1.9480	7709	
	10:30	1.9900	7700	
	11:30	2.0310	7692	
	12:30 P.M.	2.0520	7688	
	1:30	2.0730	7683	
	2:30	2.1560	7680	
	3:00	2.1770	7680	
	4:00	2.2190	7675	
	5:00	2.2600	7675	
	6:00	2.3020	7671	
	7:00	2.3440	7671	
	8:00	2.3850	7671	
	9:00	2.4270	7671	60 hrs. Shut well in.

TABLE IV--Continued

Pressure Buildup						
Date	Time	Elapsed Time Hours	Elapsed Time Days	Surface DWT Press. Psig.	Bottom Hole Press. Psig.	Remarks
3-26-64	9:00 P.M.	0	0	4745	7671	Shut well in.
	9:01	-	.0007	6480	--	
	9:02	-	.0014	6510	--	
	9:03	-	.0021	6530	--	
	9:04	-	.0028	6535	--	
	9:05	-	.0034	6542	--	
	9:07-1/2	.125	.0052	6547	7960	
	9:10	.167	.0069	6551	--	
	9:15	.250	.0104	6552	7977	
	9:22-1/2	.370	.0156	6556	6985	
	9:30	.500	.0208	6555	7989	
	9:37-1/2	.620	.0260	6555	7994	
	9:45	.750	.0312	6554	7994	
	10:00	1.000	.0417	6554	7994	
	10:15	1.250	.0521	6552	7994	
	10:30	1.500	.0625	6551	7994	
	10:45	1.750	.0729	6550	7994	
	11:00	2.000	.0833	6548	7994	
	11:30	2.500	.1042	6548	7994	
	12:00 A.M.	3.000	.1250	6548	7994	
	12:30	3.500	.1458	6548	7994	
	1:00	4.000	.1667	6549	7994	
	1:30	4.500	.1875	6550	7994	
	2:00	5.000	.2083	6552	7994	
	2:30	5.500	.2292	6555	7989	
	3:00	6.000	.2400	6562	7985	
	3:30	6.500	.2708	6566	7977	
	4:00	7.000	.2917	6570	7977	
	4:30	7.500	.3125	6575	7977	
	5:00	8.000	.3333	6578	7977	
	5:30	8.500	.3542	6579	7973	
	6:00	9.000	.3750	6580	7968	
	6:30	9.500	.3958	6583	7968	
	7:00	10.000	.4167	6585	7968	
	7:30	10.500	.4375	6586	7968	
	8:00	11.000	.4583	6586	7968	
	8:30	11.500	.4792	6586	7968	
	9:00	12.000	0.5000	6586	7968	Started out of hole.

TABLE IV--Continued

Static Pressures 15,000# Element			
Depth	Bottom Hole Press. Psig.	ΔP	Gradient (Psi/ft.)
0	6627	--	--
10,500	7993	--	--
11,000	8018	25	.050
11,500	8068	50	.100
11,780	8102	34	.121
11,835			

TABLE V

PRESENT WORTH

STRAIGHT DEPLETION OF PRESSURE

AT CURRENT RATE

Year	Condensate Bbls	Wet Gas MMSCF	Gross Income	Oper. Costs	Undeferred Net Income	Deferred Net Profit
1	617490	9346	3052287	124439	2927848	2842940
2	585247	9346	2973627	120005	2853622	2616770
3	547395	9346	2881280	114801	2766479	2390240
4	511787	9346	2794409	109904	2684505	2190556
5	482908	9346	2623995	105934	2618061	2013290
6	456178	9346	2658742	102258	2556484	1856000
7	429448	9346	2593532	98593	2494949	1790040
8	409448	9346	2543778	95834	2447944	1581370
9	389447	9346	2495943	93084	2402859	1465640
10	272718	9346	2455130	90784	2364346	1359500
11	356082	9346	2414540	88494	2326046	1263040
12	342718	9346	2381940	86658	2295282	1175185
13	333745	9346	2360050	85424	2274626	1098645
14	318231	9346	2322200	83291	2238909	1020940
15	311502	9346	2305784	82364	2223420	953850
16	300380	9346	2278650	80836	2197814	890150
17	295987	9346	2267933	80234	2187699	835700
18	289259	9346	2241420	79307	2172213	784170
19	282623	9346	2235330	78394	2156936	733360
20	278137	9346	2224385	77778	2146607	689060
21	273744	9346	2213668	77174	2136494	647360
22	271501	9346	2208195	76864	2131331	609460
23	267015	9346	2197250	76249	2121001	572670
24	262623	9346	2186533	75644	2110889	563165
25	260380	9346	2181064	75334	2104730	505375
26	258136	9346	2175589	75028	2100561	474725
27	255893	9346	2170117	74719	2094398	448415
28	255893	9346	2170117	74719	2095398	423875
29	253650	9346	2164646	74411	2090235	397145
30	251407	9346	2159172	74102	2085070	375310

TABLE V--Continued

Year	Condensate Bbls	Wet Gas MMSCF	Gross Income	Oper. Costs	Undeferred Net Income	Deferred Net Profit
31	250380	9346	2146667	73961	2082706	347810
32	249258	9346	2153930	73807	2080123	330740
33	248136	9346	2151190	13653	2077537	313710
34	244770	9346	2142980	73190	2069790	293910
35	244770	9346	2142980	73190	2069790	277351
36	244770	9346	2142980	73190	2069790	262860
37	244770	9346	2142980	73190	2069790	246300
38	244770	9346	2142980	73190	2069790	233890
39	244770	9346	2142980	73190	2069790	219400
40	244770	9346	2142980	73190	2069790	206979
41	244770	9346	2142980	73190	2069790	195180
42	244770	9346	2142980	73190	2069790	184830
43	244770	9346	2142980	73190	2069790	173860
44	244770	9346	2142980	73190	2069790	164340
45	244770	9346	2142980	73190	2069790	154820
46	244770	9346	2142980	73190	2069790	146334
47	244770	9346	2142980	73190	2069790	140124
48	244770	9346	2142980	73190	2069790	130600
49	244770	9346	2142980	73190	2069790	123150
50	244770	9346	2142982	73190	2069790	115910
TOTAL	15429856	467300				38749249

TABLE VI

PRESENT WORTH

PRESSURE MAINTENANCE WITH GAS CYCLING

40 MMSCF PER DAY

Years	Condensate Bbls	Wet Gas MMSCF	Gross Income	Oper. Costs	Undeferred Net Income	Deferred Net Profit
1	1000000		2439650	441500	1998150	(-2059800)
2	1000000		2439650	441500	1998150	(-227497)
3	1000000		2439650	441500	1998150	1498900
4	1000000		2439650	441500	1998150	1630490
5	1000000		2439650	441500	1998150	1536600
6	1000000		2439650	441500	1998150	1450660
7	1000000		2439650	441500	1998150	1368700
8	1000000		2439650	441500	1998150	1290800
9	1000000		2439650	441500	1998150	1218900
10	1000000		2439650	441500	1998150	1149000
11	1000000		2439650	441500	1998150	1085000
12	1000000		2439650	441500	1998150	1023000
13	1000000		2439650	441500	1998150	965100
14	1000000		2439650	441500	1998150	911160
15	1000000		2439650	441500	1998150	857200
16	1000000		2439650	441500	1998150	809250
17	1000000		2439650	441500	1998150	763300
18	1000000		2439650	441500	1998150	721300
19	1000000		2439650	441500	1998150	679370
20	920000		2244500	430500	1814000	641400
21	890000		2171300	426375	1744925	605440
22	860000		2098100	422250	1675850	571500
23	830000		2024900	418125	1606775	539500
24	810000		1976100	415375	1560725	507500
25	780000		1902900	411250	1491650	479560
26	750000		1829700	407125	1422575	451580
27	730000		1780900	404375	1376525	427600
28	710000		1732200	401625	1330575	403630
29	690000		1683400	398875	1284525	379650
30	670000		1634600	396125	1238475	359670
UBTOTAL	27640000					24325760
RESERVOIR BLOWDOWN						
80	10450000	482.3	105625267	3446150	102179117	5687293
TOTAL	38090000	482.3				30013053

TABLE VII

PRESENT WORTH

GAS CYCLING WITH PRESSURE DEPLETION

GAS SALES AT CURRENT RATE

Year	Condensate Bbls	Wet Gas MMSCF	Gross Income	Oper. Costs	Undeferred Net Income	Deferred Net Profit
1	1605475	9345.6	5462600	564285	4898315	(-243735)
2	1521642	9345.6	5258100	552760	4705340	4071065
3	1423230	9345.6	5018000	539230	4478770	3869660
4	1330646	9345.6	4792100	526500	4265600	3480730
5	1255560	9345.6	4608950	516175	4092775	3147350
6	1186062	9345.6	4439400	506620	3932780	2855200
7	1116565	9345.6	4269860	497065	3772795	2584360
8	1064565	9345.6	4143000	389913	3653086	2359900
9	1012562	9345.6	4016130	482765	3533365	2155350
10	969067	9345.6	3910000	476785	3433215	1974100
11	925813	9345.6	3804500	470835	3333665	1810180
12	891067	9345.6	3719700	466055	3253645	1665870
13	867737	9345.6	3662800	462845	3199955	1545600
14	744660	9345.6	3362540	445925	2916615	1330000
15	688420	9345.6	3225330	439193	2787137	1195700
16	632300	9345.6	3088420	430475	2657945	1076467
17	588720	9345.6	2982100	424485	2557615	977000
18	545253	9345.6	2876060	418535	2456525	887170
19	510700	9345.6	2791760	413755	2378005	808521
20	477280	9345.6	2710244	409165	2301079	738810
21	273744	9345.6	2213670	77175	2136495	647360
22	271500	9345.6	2208200	76865	1231335	609560
23	267015	9345.6	2197250	76265	2120985	572670
24	262623	9345.6	2186540	75645	2110895	536170
25	260380	9345.6	2181060	75335	2105725	505375
26	258136	9345.6	2175600	75025	2100575	474730
27	255893	9345.6	2170120	74720	2095400	448415
28	255893	9345.6	2170120	74720	2095400	523270
29	253650	9345.6	2164650	74410	2090240	397145
30	241407	9345.6	2149170	74105	2085065	375310

TABLE VII--Continued

Year	Condensate Bbls	Wet Gas MMSCF	Gross Income	Oper. Costs	Undeferred Net Income	Deferred Net Profit
31	250380	9345.6	2156670	73965	2082705	347810
32	249248	9345.6	2153930	73805	2080125	330740
33	248136	9345.6	2151190	73665	2077535	313700
34	244770	9345.6	2143000	73190	2069810	293910
35	244770	9345.6	2143000	73190	2069810	277350
36	244770	9345.6	2143000	73190	2069810	262870
37	244770	9345.6	2143000	73190	2069810	246300
38	244770	9345.6	2143000	73190	2069810	233900
39	244770	9345.6	2143000	73190	2069810	219400
40	244770	9345.6	2143000	73190	2069810	207000
41	244770	9345.6	2143000	73190	2069810	195180
42	244770	9345.6	2143000	73190	2069810	184800
43	244770	9345.6	2143000	73190	2069810	173860
44	244770	9345.6	2143000	73190	2069810	164340
45	244770	9345.6	2143000	73190	2069810	154820
46	244770	9345.6	2143000	73190	2069810	146340
47	244770	9345.6	2143000	73190	2069810	140130
48	244770	9345.6	2143000	73190	2069810	130600
49	244770	9345.6	2143000	73190	2069810	123150
50	244770	9345.6	2143000	73190	2069810	115900
TOTAL	26876429	467280				47784138

TABLE VIII

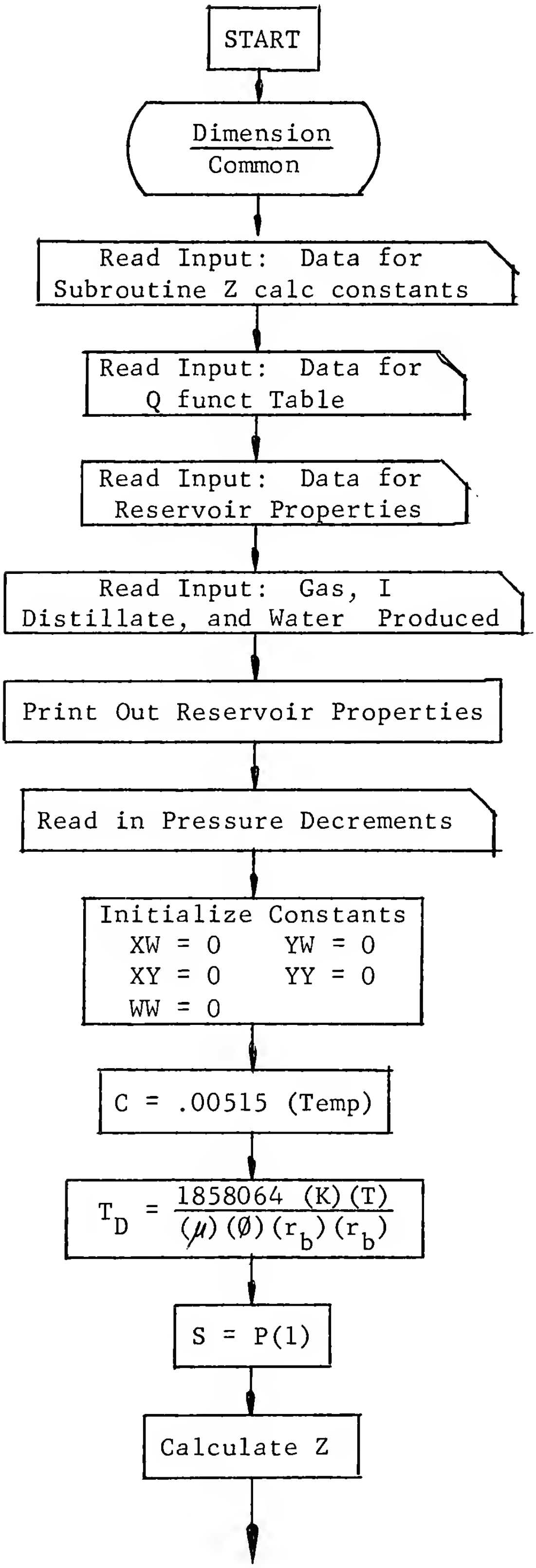
CAPITAL EXPENDITURES

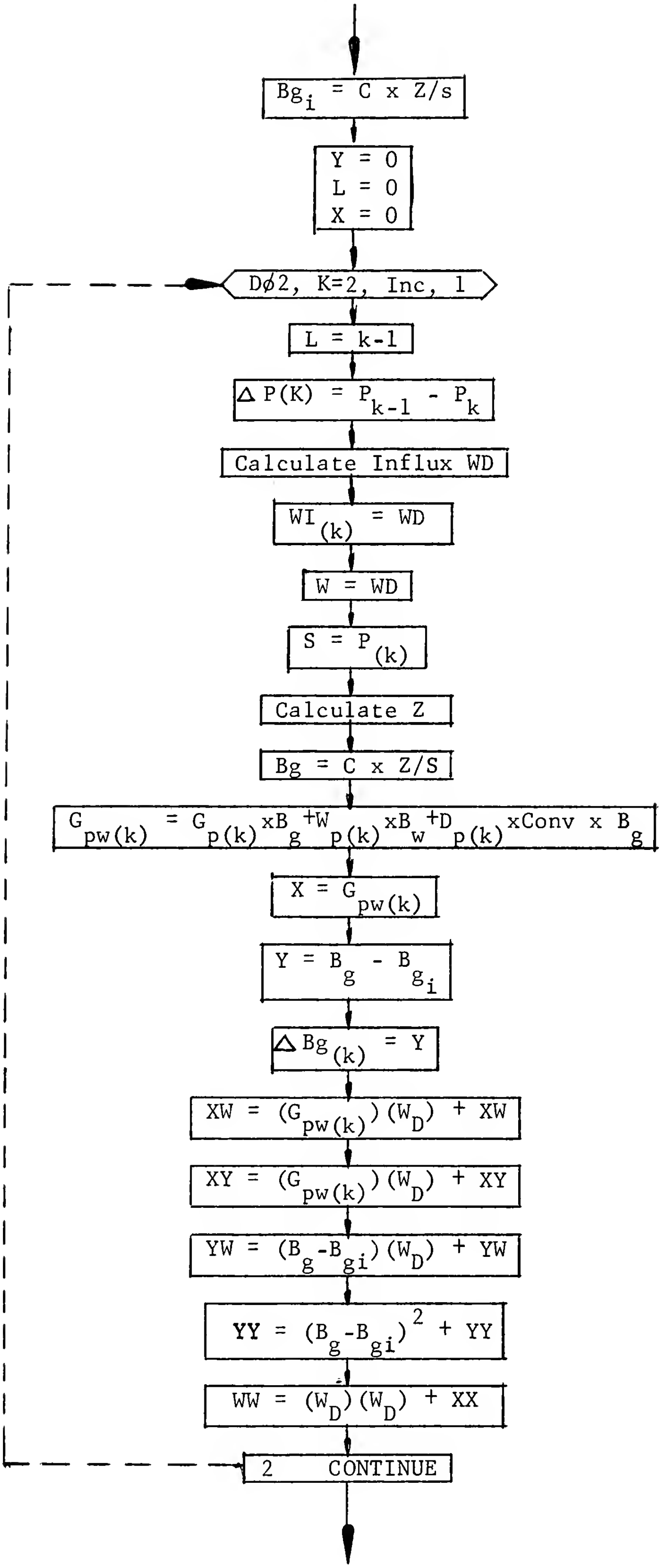
Pressure Maintenance - Cycling without gas sales			
	Recomplete 9	$ 70,000	
	New Well 11	600,000	
	Recomplete 10	70,000	
	New Well 5	600,000	
	Recomplete 4	70,000	
	Well 6	0	
			$1,410,000
Platform			
	Fabrication	320,000	
	Installation	80,000	
			$ 400,000
Compressors			
	Fabrication	1,116,000	
	Installation	90,000	
			$1,206,000
Pipe			
	High pressure line	25,000	
	Sales gas line	100,000	
			$ 125,000
Separation Facilities			$ 971,500
			$4,000,000
Additional Plant Required for Normal Cycling			
	New well	$ 700,000	
	Sales gas line	300,000	
			$1,000,000
Total for normal gas cycling			$5,000,000

APPENDIX I

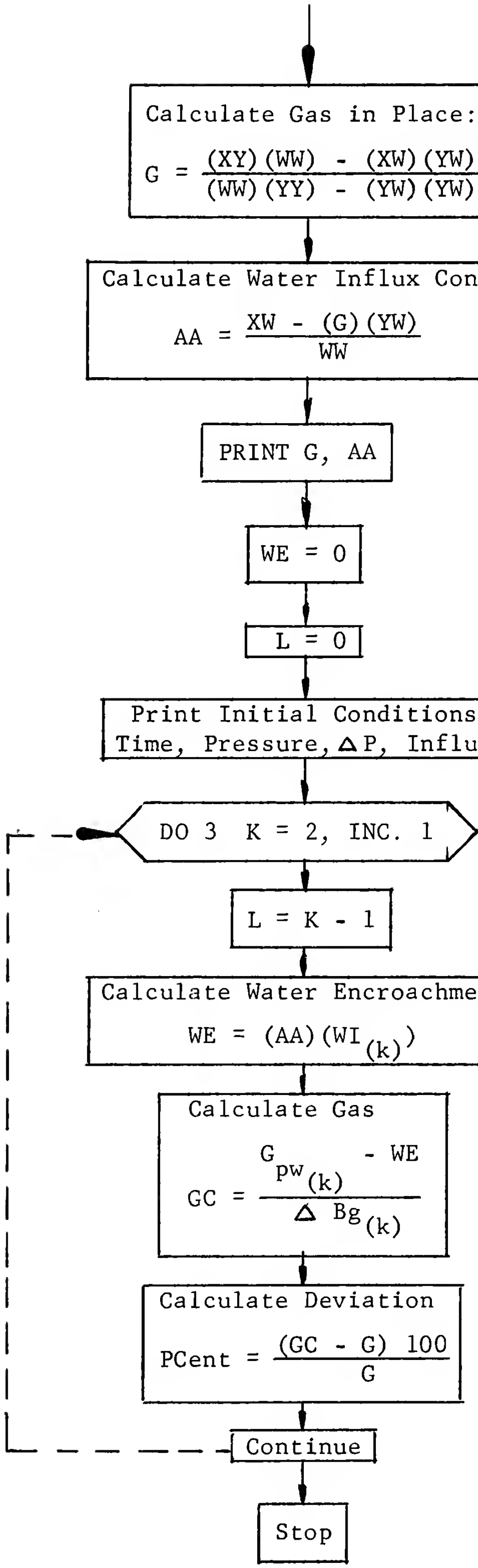
MATERIAL BALANCE CALCULATION

GAS RESERVE CALCULATION PROGRAM





Bgi = C x Z/s
Y = 0
L = 0
X = 0
DØ2, K=2, Inc, 1
L = k-1
ΔP(K) = Pk-1 - Pk
Calculate Influx WD
WI(k) = WD
W = WD
S = P(k)
Calculate Z
Bg = C x Z/S
Gpw(k) = Gp(k) xBg +Wp(k) xBw +Dp(k) xConv x Bg
X = Gpw(k)
Y = Bg - Bgi
ΔBg(k) = Y
XW = (Gpw(k)) (WD) + XW
XY = (Gpw(k)) (WD) + XY
YW = (Bg -Bgi) (WD) + YW
YY = (Bg -Bgi)2 + YY
WW = (WD) (WD) + XX
2 CONTINUE


Calculate Gas in Place:
G = (XY) (WW) - (XW) (YW) / (WW) (YY) - (YW) (YW)
Calculate Water Influx Constant:
AA = XW - (G) (YW) / WW
PRINT G, AA
WE = 0
L = 0
Print Initial Conditions
Time, Pressure, ΔP, Influx
DO 3 K = 2, INC. 1
L = K - 1
Calculate Water Encroachment
WE = (AA) (WI (k))
Calculate Gas
GC = G pw (k) - WE / Δ Bg (k)
Calculate Deviation
PCent = (GC - G) 100 / G
Continue
Stop

```
      PROGRAM GASRES
      DIMENSION A(6,6),B(6),T(381),Q(381),DELP(20),P(20),GP(20),DP(20
      DIMENSION WP(20),GPW(20),WI(20),DELBG(20)
      COMMON A,B,TEMP,PC,TC,T,Q,K,DELP
      PRINT 800
  800 FORMAT(1H1)
      PRINT 101
  101 FORMAT(44H RESERVOIR COMPUTER PROJECT---ENERGY BALANCE,//)
C     DATA INPUT FOR SUBROUTINE ZCALC CONSTANTS
      DO 1000 J=1,6,1
      DO 1000 I=1,6,1
      READ 200,A(I,J)
  200 FORMAT(13X,F14.11)
 1000 CONTINUE
      DO 1010 I=1,6,1
      READ 201,B(I)
  201 FORMAT(F14.11)
 1010 CONTINUE
C     DATA INPUT FOR SUBROUTINE QFUNCT TABLE
      DO 1020 I=1,381,3
      READ 202,T(I),Q(I),T(I+1),Q(I+1),T(I+2),Q(I+2)
  202 FORMAT(F12.2,F12.3,F12.2,F12.3,F12.2,F12.3)
 1020 CONTINUE
C     DATA INPUT FOR RESERVOIR PROPERTIES
      READ 203,AIWEL
      READ 203,CONV
      READ 203,RI
      READ 203,DEPTH
      READ 203, TEMP
      READ 203,SGI
      READ 203,O
      READ 203,AH
      READ 203,SG
      READ 203,U
      READ 203,AK
      READ 203,TIME
      READ 203,SGR
      READ 203,SWC
      READ 203,PI
      READ 203,PC
      READ 203,TC
      READ 203,BW
      READ 203,CPI
  203 FORMAT(F16.7)
      INC=CPI
C     DATA INPUT FOR RESERVOIR PRODUCTION
      DO 1030 I=1,INC,1
      READ 204,GP(I),DP(I),WP(I)
  204 FORMAT (3F20.0)
 1030 CONTINUE
      PRINT 102
  102 FORMAT(19H RESERVOIR DATA FOR,/)
C     DATA PRINT OUT FOR RESERVOIR PROPERTIES
      PRINT 300,INC
  300 FORMAT(45H INC,CURRENT NUMBER OF PRODUCTION INCREMENTS=,I4)
      PRINT 301,AIWEL
```

```
  301 FORMAT(48H MAX. NUMBER OF PRODUCING WELLS AT ANY ONE TIME=,F6.1)
      PRINT 302,BW
  302 FORMAT(50H BW,FORMATION VOLUME FACTOR FOR WATER IN BBLS/STB=,F6.3)
      PRINT 303,CONV
  303 FORMAT(44H CONV,SCF OF VAPOR PER BARREL OF DISTILLATE=,F7.1)
      PRINT 304,RI
  304 FORMAT(48H RI,RADIUS TO INITIAL EDGE OF RESERVOIR IN FEET=,F8.1)
      PRINT 305,DEPTH
  305 FORMAT(34H DEPTH,DEPTH OF RESERVOIR IN FEET=,F8.1)
      PRINT 306,TEMP
  306 FORMAT(50H TEMP,TEMPERATURE OF RESERVOIR IN DEGREES RANKINE=,F7.1)
      PRINT 307,PC
  307 FORMAT(36H PC,PSEUDOCRITICAL PRESSURE IN PSIA=,F6.1)
      PRINT 308,TC
  308 FORMAT(50H TC,PSEUDOCRITICAL TEMPERATURE IN DEGREES RANKINE=,F6.1)
      PRINT 309,SGI
  309 FORMAT(40H SGI,INITIAL GAS SATURATION AS FRACTION=,F5.3)
      PRINT 310,O
  310 FORMAT(24H O,POROSITY AS FRACTION=,F5.3)
      PRINT 311,AH
  311 FORMAT(43H AH,AVERAGE THICKNESS OF RESERVOIR IN FEET=,F6.1)
      PRINT 312,SG
  312 FORMAT(44H SG,SPECIFIC GRAVITY OF GAS RELATIVE TO AIR=,F7.4)
      PRINT 313,U
  313 FORMAT(46H U,VISCOSITY OF RESERVOIR WATER IN CENTIPOISE=,F6.3)
      PRINT 314,AK
  314 FORMAT(47H AK,WATER PERMEABILITY OF RESERVOIR IN DARCIES=,F7.4)
      PRINT 315,TIME
  315 FORMAT(33H TIME,TIME INTERVAL USED IN DAYS=,F7.2)
      PRINT 316,SGR
  316 FORMAT(41H SGR,RESIDUAL GAS SATURATION AS FRACTION=,F5.3)
      PRINT 317,SWC
  317 FORMAT(42H SWC,CONNATE WATER SATURATION AS FRACTION=,F5.3)
      PRINT 802
  802 FORMAT(1H ,/)
C     DATA INPUT FOR RESERVOIR PRESSURE
    1 DO 1040 I=1,INC,1
      READ 205,P(I)
  205 FORMAT(F10.3)
 1040 CONTINUE
C     MAIN BODY OF PROGRAM WITH CALCULATIONS
      PRINT 103
  103 FORMAT(16H TIME   PRESSURE,9X,1HZ,10X,10HBG,BBL/SCF,8X,6HDEL BG,6X
     1,14HRES. WITH.,BBL)
      DELP(1)=0.0
      XW=0.0
      YW=0.0
      XY=0.0
      YY=0.0
      WW=0.0
      C=0.00514590*TEMP
      DELTD=1858064.0*AK*TIME/(U*O*RI*RI)
      S=P(1)
      CALL ZCALC(S,Z)
      BGI=C*Z/S
      Y=0.0
```

```
      L=0
      X=0.0
      PRINT 400,L,S,Z,BGI,Y,X
  400 FORMAT(I5,2X,F10.3,2X,E14.8,2X,E14.8,2X,E14.8,2X,E14.8)
      DO 2 K=2,INC,1
      L=K-1
      DELP(K)=P(K-1)-P(K)
      CALL INFLUX(DELTD,WD)
      WI(K)=WD
      W=WD
      S=P(K)
      CALL ZCALC(S,Z)
      BG=C*Z/S
      GPW(K)=GP(K)*BG+WP(K)*BW+DP(K)*CONV*BG
      X=GPW(K)
      Y=BG-BGI
      DELBG(K)=Y
      XW=X*W+XW
      XY=X*Y+XY
      YW=Y*W+YW
      YY=Y*Y+YY
      WW=W*W+WW
      PRINT 400,L,S,Z,BG,Y,X
    2 CONTINUE
      G=((XY*WW)-(XW*YW))/((WW*YY)-(YW*YW))
      AA=(XW-G*YW)/WW
      PRINT 401,G,AA
  401 FORMAT(1H ,//,14H L.M.S. G,SCF=,E14.8,/,23H WATER INFLUX CONSTANT=
     2,E14.8,//)
      PRINT 104
  104 FORMAT(16H TIME    PRESSURE,6X,5HDEL P,3X,14HWATER INFL,BBL,2X,14HP
     3ERIODIC G CHK,2X,12HPERCENT DEV.)
      WE=0.0
      L=0
      PRINT 402,L,PI,DELP(1),WE
  402 FORMAT(I5,2X,F10.3,2X,F10.3,2X,E14.8)
      DO 3 K=2,INC,1
      L=K-1
      WE=AA*WI(K)
      GC=(GPW(K)-WE)/DELBG(K)
      PCENT=(GC-G)*100.0/G
      PRINT 403,L,P(K),DELP(K),WE,GC,PCENT
  403 FORMAT(I5,2X,F10.3,2X,F10.3,2X,E14.8,2X,E14.8,2X,F10.4)
    3 CONTINUE
      PRINT 801
  801 FORMAT(1H ,/////)
      PRINT 800
      CONTINUE
      GO TO 1
      END
```

```
      SUBROUTINE ZCALC(S,Z)
      DIMENSION A(6,6),B(6),T(381),Q(381),DELP(20),P(20),GP(20),DP(20)
      DIMENSION PX(6),PY(6)
      COMMON A,B,TEMP,PC,TC,T,Q,K,DELP
      Y=((2.0*TEMP/TC)-4.0)/1.9
      PY(1)=B(1)
      PY(2)=B(2)*Y
      PY(3)=B(3)*((3.0*Y*Y)-1.0)
      PY(4)=B(4)*((5.0*Y*Y)-3.0)*Y
      PY(5)=B(5)*(((35.0*Y*Y)-30.0)*Y*Y+3.0)
      PY(6)=B(6)*((((63.0*Y*Y)-70.0)*Y*Y)+15.0)*Y
      X=((2.0*S/PC)-15.0)/14.8
      PX(1)=B(1)
      PX(2)=B(2)*X
      PX(3)=B(3)*((3.0*X*X)-1.0)
      PX(4)=B(4)*((5.0*X*X)-3.0)*X
      PX(5)=B(5)*((((35.0*X*X)-30.0)*X*X)+3.0)
      PX(6)=B(6)*((((63.0*X*X)-70.0)*X*X)+15.0)*X
      APP=0.0
      DO 1 M=1,6,1
      DO 1 N=1,6,1
    1 APP=(A(N,M)*PX(M)*PY(N))+APP
      Z=APP
      RETURN
      END
```

```
      SUBROUTINE QFUNCT(DELT,QT)
      DIMENSION A(6,6),B(6),T(381),Q(381),DELP(20),P(20),GP(20),DP(20)
      COMMON A,B,TEMP,PC,TC,T,Q,K,DELP
      TT=DELT
      DO 3 I=1,381,1
      IF(TT-T(I)) 1,2,3
    1 DQ1=(Q(I-1)-Q(I-2))/(T(I-1)-T(I-2))
      DQ2=((Q(I)-Q(I-1))/(T(I)-T(I-1))-DQ1)/(T(I)-T(I-2))
      QT=Q(I-2)+(TT-T(I-2))*DQ1+(TT-T(I-2))*(TT-T(I-1))*DQ2
      GO TO 4
    2 QT=Q(I)
      GO TO 4
    3 CONTINUE
    4 RETURN
      END
         END        GASRES
```

```
      SUBROUTINE INFLUX(DELTD,WD)
      DIMENSION A(6,6),B(6),T(381),Q(381),DELP(20),P(20),GP(20),DP(20)
      COMMON A,B,TEMP,PC,TC,T,Q,K,DELP
      WD=0.0
      DO 1 J=1,K,1
      TI=J-1
      DELT=TI*DELTD
      CALL QFUNCT(DELT,QT)
      N=K+1-J
      WI=DELP(N)*QT
      WD=WI+WD
    1 CONTINUE
      RETURN
      END
```

RESERVOIR COMPUTER PROJECT---ENERGY BALANCF

RESERVOIR DATA FOR

INC,CURRENT NUMBER OF PRODUCTION INCREMENTS= 13
MAX. NUMBER OF PRODUCING WELLS AT ANY ONE TIME= 2.0
BW,FORMATION VOLUME FACTOR FOR WATER IN BBLS/STB= 1.030
CONV,SCF OF VAPOR PER BARREL OF DISTILLATE= 768.0
RI,RADIUS TO INITIAL EDGE OF RESERVOIR IN FEET= 2190.0
DEPTH,DEPTH OF RESERVOIR IN FEET= 11450.0
TEMP,TEMPERATURE OF RESERVOIR IN DEGREES RANKINE= 690.0
PC,PSEUDOCRITICAL PRESSURE IN PSIA= 662.3
TC,PSEUDOCRITICAL TEMPERATURE IN DEGREES RANKINE= 387.5
SGI,INITIAL GAS SATURATION AS FRACTION= .800
O,POROSITY AS FRACTION= .280
AH,AVERAGE THICKNESS OF RESERVOIR IN FEET= 64.4
SG,SPECIFIC GRAVITY OF GAS RELATIVE TO AIR= .7975
U,VISCOSITY OF RESERVOIR WATER IN CENTIPOISE= .300
AK,WATER PERMEABILITY OF RESERVOIR IN DARCIES= .0500
TIME,TIME INTERVAL USED IN DAYS= 90.00
SGR,RESIDUAL GAS SATURATION AS FRACTION= .300
SWC,CONNATE WATFR SATURATION AS FRACTION= .150

TIME	PRESSURE	Z	BG,BBL/SCF	RES. WITH.,BBL
0	8838.000	1.32981926E 00	5.34255563E-04	0
1	8818.000	1.32803329E 00	5.34748162E-04	3.03008359E 05
2	8764.000	1.32322017E 00	5.36093049E-04	1.14994894E 06
3	8717.000	1.31904095E 00	5.37281226E-04	1.64549602E 06
4	8657.000	1.31371808E 00	5.38821841E-04	2.62736394E 06
5	8582.000	1.30708189E 00	5.40785103E-04	3.89883102E 06
6	8509.000	1.30063895E 00	5.42736044E-04	5.12844213E 06
7	8440.000	1.29456183E 00	5.44616486E-04	6.35037990E 06
8	8364.000	1.28788050E 00	5.46728833E-04	7.69974695E 06
9	8289.000	1.28129781E 00	5.48855951E-04	8.91284897E 06
10	8219.000	1.27516200E 00	5.50879758E-04	9.81497565E 06
11	8155.000	1.26955778E 00	5.52762967E-04	1.09665134E 07
12	8100.000	1.26474529E 00	5.54406719E-04	1.21921223E 07

L.M.S. G,SCF=6.06624695E 11
WATER INFLUX CONSTANT=4.0706801*E 00

TIME	PRESSURE	DEL P	WATER INFL,BBL	PERIODIC G CHK
1	8818.000	20.000	0	6.15121449E 11
2	8764.000	54.000	1.0311549*E 03	6.26388336E 11
3	8717.000	47.000	4.5347547*E 03	5.45345143E 11
4	8657.000	60.000	9.5550091*E 03	5.77476619E 11
5	8582.000	75.000	1.6725031*E 04	5.99668013E 11
6	8509.000	73.000	2.6552691*E 04	6.07865842E 11
7	8440.000	69.000	3.8609296*E 04	6.16642836E 11
8	8364.000	76.000	5.2608605*E 04	6.21517492E 11
9	8289.000	75.000	6.8905530*E 04	6.15172299E 11
10	8219.000	70.000	8.7297406*E 04	5.95654287E 11
11	8155.000	64.000	1.0748285*E 05	5.98354920E 11
12	8100.000	55.000	1.2918882*E 05	6.11444376E 11

APPENDIX II

FLUID DATA

HYDROCARBON ANALYSES OF SEPARATOR PRODUCTS

AND CALCULATED WELL STREAM

	Separator Liquid		Separator Gas		Well Stream	
Component	Mol %	Liq. Vol. %	Mol %	GPM@ 15.025 PSIA	Mol %	GPM@ 15.025 PSIA
Carbon Dioxide	---	---	0.70		0.67	
Nitrogen	---	---	0.32		0.30	
Methane	21.59	5.59	93.34		89.90	
Ethane	4.13	1.44	3.53		3.56	
Propane	3.87	1.95	1.24	0.349	1.37	0.385
Iso-Butane	2.05	1.23	0.35	0.117	0.43	0.144
N-Butane	2.29	1.32	0.25	0.081	0.35	0.113
Iso-Pentane	1.47	0.99	0.11	0.041	0.17	0.063
N-Pentane	1.68	1.12	0.05	0.018	0.13	0.048
Hexanes	4.82	3.63	0.07	0.029	0.30	0.126
Heptanes Plus	58.10	82.73	0.04	0.019	2.82	2.233
Totals	100.00	100.00	100.00	0.654	100.00	3.112

Calculated Specific Gravity (Air = 1.00)	0.606	0.7975

Properties of Heptanes Plus:

API Gravity = 39.9°API @ 60°F
Specific Gravity = 0.8256 @ 60/60°F
Molecular Weight = 202

Basis of Recombination:

Separator Liquid per MMSCF Separator Gas = 66.07 Bbls

PRESSURE-VOLUME RELATIONS OF RESERVOIR FLUID AT 240°F
(CONSTANT COMPOSITION EXPANSION)

Pressure (PSIA)		Relative Volume (V/Vsat)	Specific Volume (Cu.Ft./Lb.)	Deviation Factor (Z)
8680		0.9793	0.04918	1.3111
8600	Original Reservoir Pressure	-	-	
8305		0.9978	0.05011	1.2782
8260	Dew Point Press.	1.0000	0.05022	1.2741
8138		1.0070	0.05057	
7825		1.0255	0.05150	
2555		1.0442	0.05244	
6930		1.0910	0.05479	
6415		1.1382	0.05716	
5990		1.1856	0.05954	
5610		1.2332	0.06193	
5295		1.2808	0.06432	
4765		1.3767	0.06914	
4168		1.5207	0.07637	
3495		1.7555	0.08816	
2675		2.2401	0.11250	
2190		2.7208	0.13663	
1855		3.2067	0.16104	
1620		3.6864	0.18513	

EFFECT OF GAS-LIQUID RATIO UPON DEW POINT PRESSURE AT 240°F

Dew Point Pressure (PSIA)	Gas-Liquid Ratio (SCF Separator Gas per Bbl Separator Liquid)
8,090	20,000
8,260	15,135
8,360	10,000

RETROGRADE CONDENSATION DURING GAS DEPLETION AT 240°F

Pressure (PSIA)		Reservoir Liquid (Bbls/MMSCF of Reservoir Fluid)	Retrograde Liquid Volume Percent *
8,600	Original Res. Pressure	0	0
8,260	Dew Point Pressure	0	0
7,500		14.09	2.48
6,500		31.55	5.55
5,500		42.33	7.45
4,500		47.03	8.27
3,000		48.64	8.56
1,500		45.57	6.68

* Percent of Reservoir Hydrocarbon Pore Space

HYDROCARBON ANALYSES OF GAS AND LIQUID REMAINING IN RESERVOIR

AFTER DEPLETION TO 1,500 PSIA at 240°F

	Reservoir Gas		Reservoir Liquid	
Component	Mol %	GPM@ 15.025 PSIA	Mol %	Liq. Vol. %
Carbon Dioxide	0.74			
Methane and Nitrogen	92.36		26.74	7.42
Ethane	3.70		3.22	1.34
Propane	1.46	0.410	1.74	0.79
Iso-Butane	0.44	0.147	0.65	0.35
N-Butane	0.31	0.100	0.65	0.34
Iso-Pentane	0.17	0.063	0.98	0.59
N-Pentane	0.11	0.041	0.74	0.44
Hexanes	0.21	0.088	1.99	1.34
Heptanes Plus	0.50	0.251	63.29	87.39
Totals	100.00	1.100	100.00	100.00

Properties of Heptanes Plus:

API Gravity = 38.1° @ 60°F
Specific Gravity = 0.8343
Molecular Weight = 222

DEPLETION STUDY AT 240°F

HYDROCARBON ANALYSES OF PRODUCED WELL STREAM (MOL PER CENT)

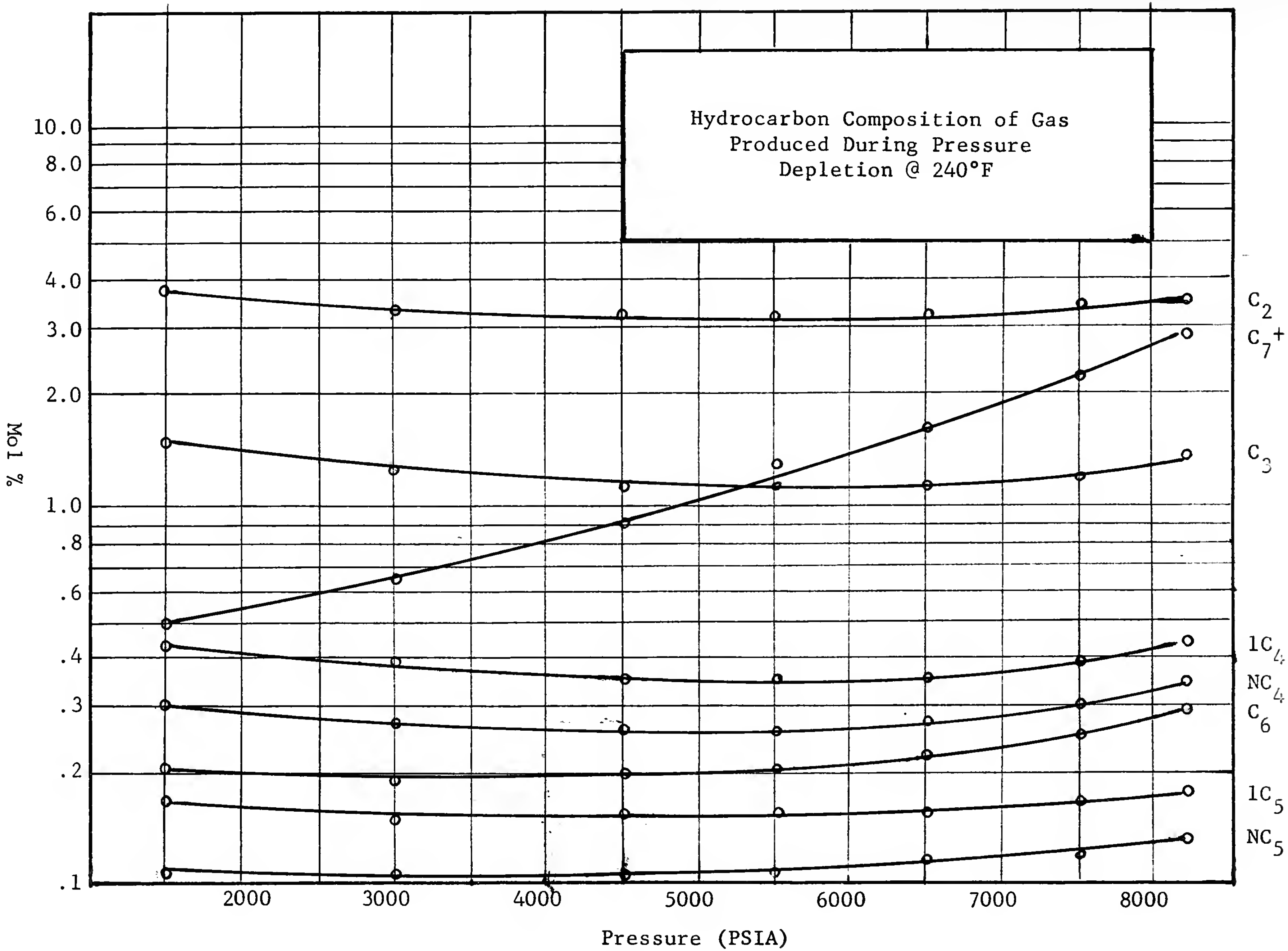
Component	Dew Point Fluid	Reservoir Pressure - PSIA					
	8260	7500	6500	5500	4500	3000	1500
Carbon Dioxide	0.67	0.73	0.84	0.78	0.75	0.78	0.74
Methane and Nitrogen	90.20	91.08	91.92	92.53	92.86	92.88	92.36
Ethane	3.56	3.41	3.29	3.20	3.24	3.31	3.70
Propane	1.37	1.24	1.12	1.15	1.15	1.27	1.46
Iso-Butane	0.43	0.39	0.36	0.35	0.35	0.39	0.44
N-Butane	0.35	0.31	0.27	0.26	0.26	0.27	0.31
Iso-Pentane	0.17	0.17	0.16	0.16	0.16	0.15	0.17
N-Pentane	0.13	0.12	0.12	0.12	0.11	0.11	0.11
Hexanes	0.30	0.27	0.23	0.21	0.20	0.19	0.21
Heptanes Plus	2.82	2.28	1.69	1.24	0.92	0.65	0.50
Totals	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Properties of Heptanes Plus							
Specific Gravity	0.8256	0.8198	0.8146	0.8058	0.7981	0.7826	0.7665
Molecular Weight	202	196	186	169	156	137	119
GPM Content of Produced Well Stream (Gal/MSCF)							
Propane	0.385	0.349	0.315	0.323	0.323	0.357	0.410
Iso-Butane	0.144	0.130	0.120	0.117	0.117	0.130	0.147
N-Butane	0.113	0.100	0.087	0.084	0.084	0.087	0.100
Iso-Pentane	0.063	0.063	0.060	0.060	0.060	0.056	0.063
N-Pentane	0.048	0.044	0.044	0.044	0.041	0.041	0.041
Hexanes	0.126	0.113	0.096	0.088	0.084	0.080	0.088
Heptanes Plus	2.233	1.764	1.249	0.841	0.582	0.368	0.251
Totals	3.112	2.563	1.971	1.557	1.291	1.119	1.100
Deviation Factor "Z"	1.280	1.210	1.126	1.054	0.992	0.927	0.932
Well Stream Produced Cumulative Per Cent	0	4.10	11.07	19.57	29.84	49.56	73.51

Constituent	Mole Fraction	Mole Weight	Pounds per Mole	Critical Temperature		Critical Pressure	
	y			T_c	yT_c	P_c	yP_c
Carbon Dioxide	.0067	44.01	.2949	548.0	3.67	1073.0	7.19
Nitrogen	.0030	28.02	.0841	227.0	.68	492.0	1.48
Methane	.8990	16.04	14.4200	343.3	308.63	673.1	605.12
Ethane	.0356	30.07	1.0705	549.8	19.57	708.3	25.22
Propane	.0137	44.09	.6040	666.0	9.12	617.4	8.46
Iso-Butane	.0043	58.12	.2499	734.7	3.16	529.1	2.28
N-Butane	.0035	58.12	.2034	765.3	2.68	550.7	1.93
Iso-Pentane	.0017	72.15	.1227	829.8	1.41	483.0	.82
N-Pentane	.0013	72.15	.0938	845.6	1.10	489.5	.64
Hexanes	.0030	86.17	.2585	896.5	2.69	440.1	1.32
Heptanes +	.0282	202.00	5.6964	1235.0	34.83	278.0	7.84
			23.0962		387.54°R		662.30

$$S.G. = \frac{23.0962}{29.0} = .7975$$

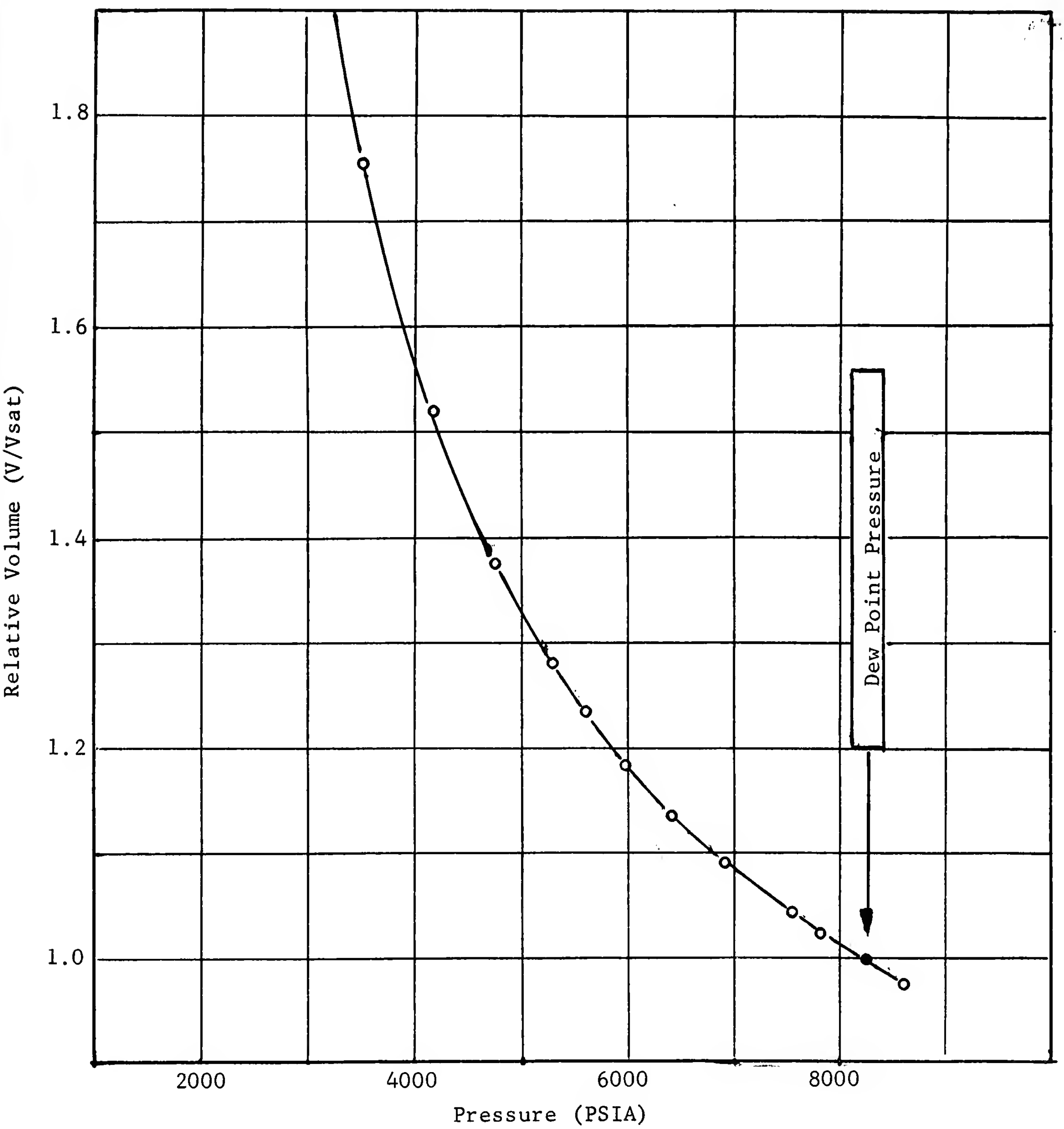
Pseudo-Critical Temperature = 387.54°R

Pseudo-critical Pressure = 662.30 PSIA



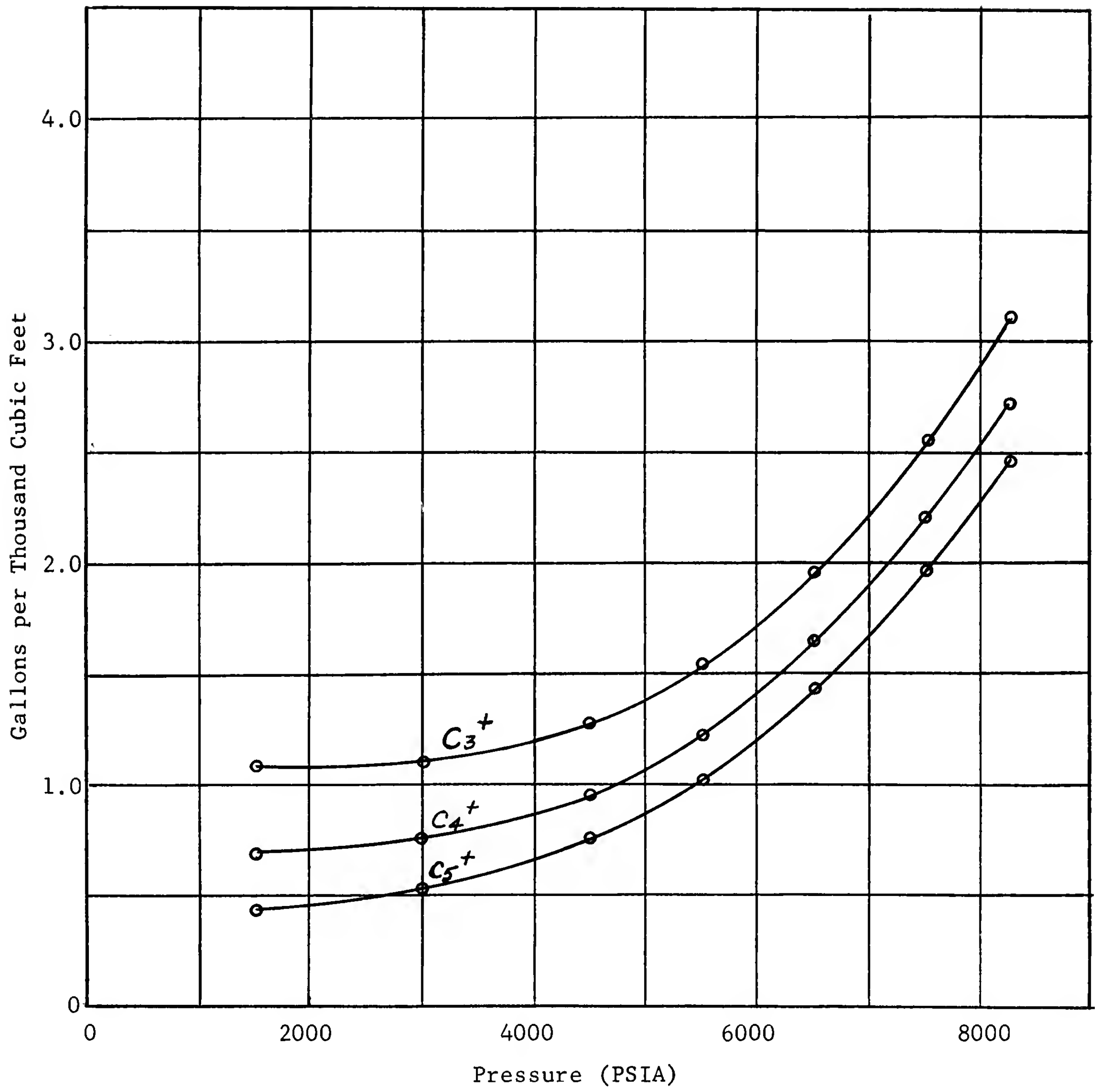
Hydrocarbon Composition of Gas Produced During Pressure Depletion @ 240°F
Mol %
10.0
8.0
6.0
4.0
3.0
2.0
1.0
.8
.6
.4
.3
.2
.1
2000
3000
4000
5000
6000
7000
8000
Pressure (PSIA)
C_2
C_7^+
C_3
$1C_4$
NC_4
C_6
$1C_5$
NC_5

PRESSURE-VOLUME RELATIONS OF RESERVOIR FLUID @ 240°F



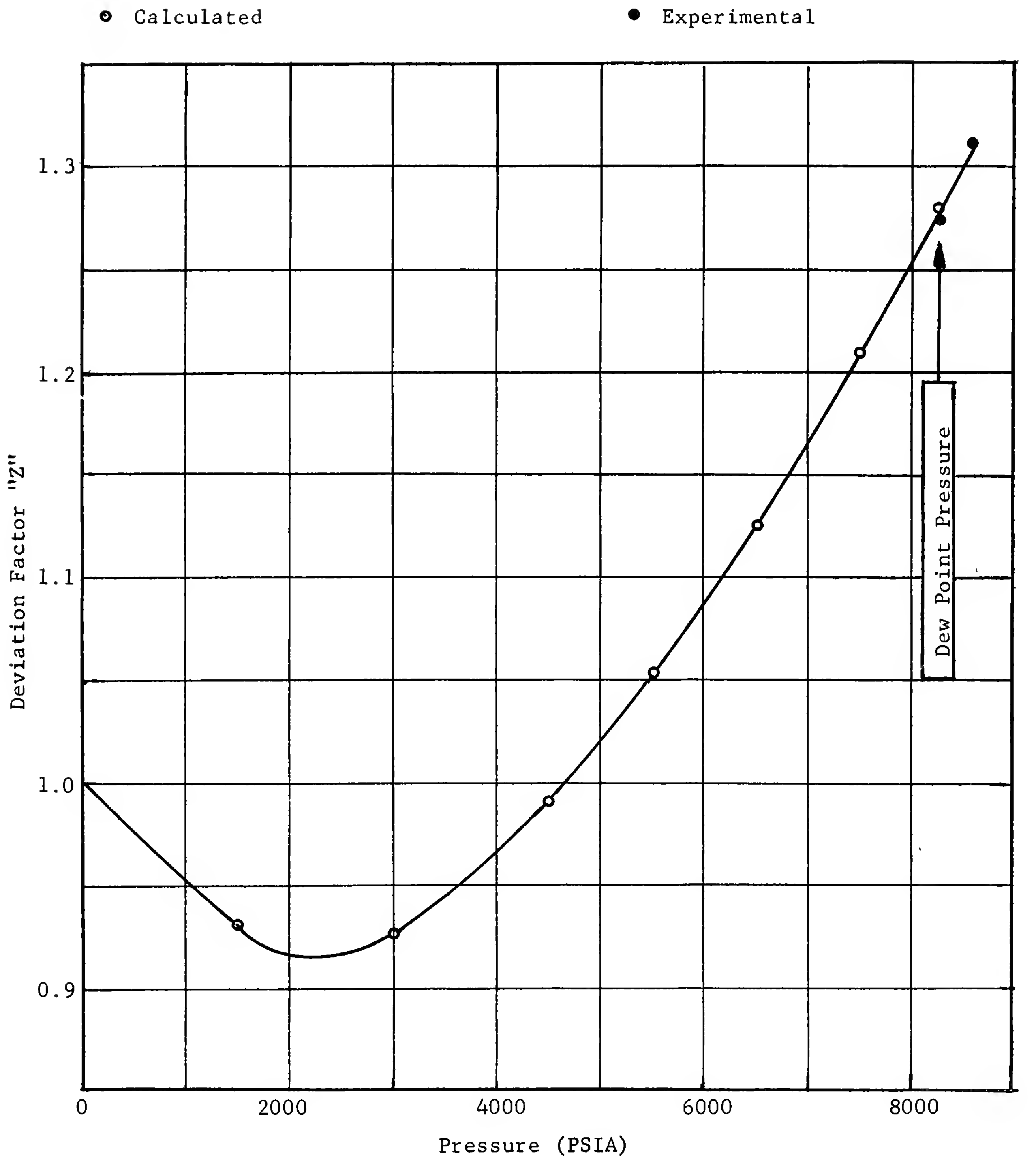
GASOLINE CONTENT OF HYDROCARBONS PRODUCED

DURING PRESSURE DEPLETION @ 240°F



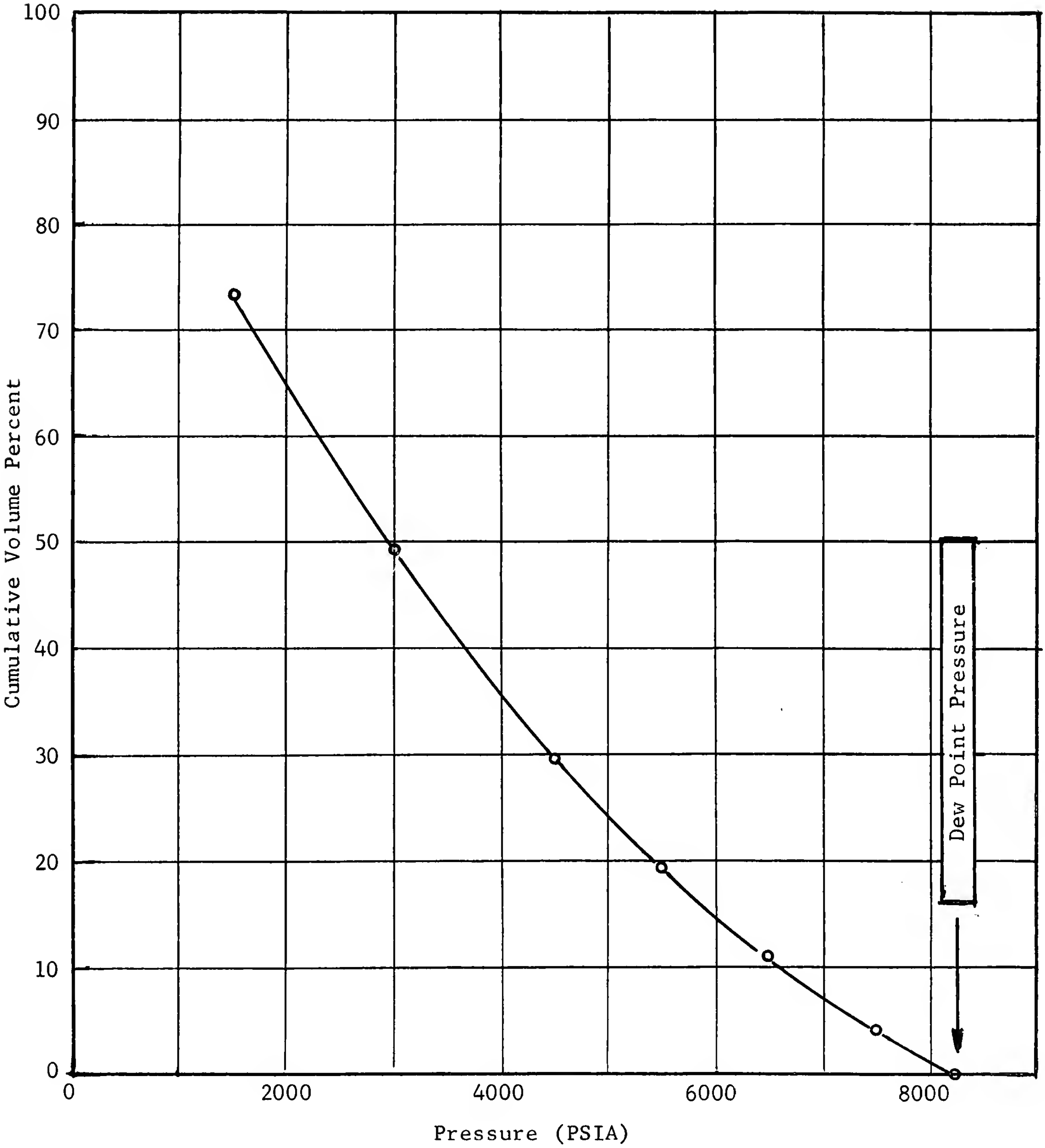
DEVIATION FACTOR "Z" OF GAS PHASE

DURING DEPLETION @ 240°F



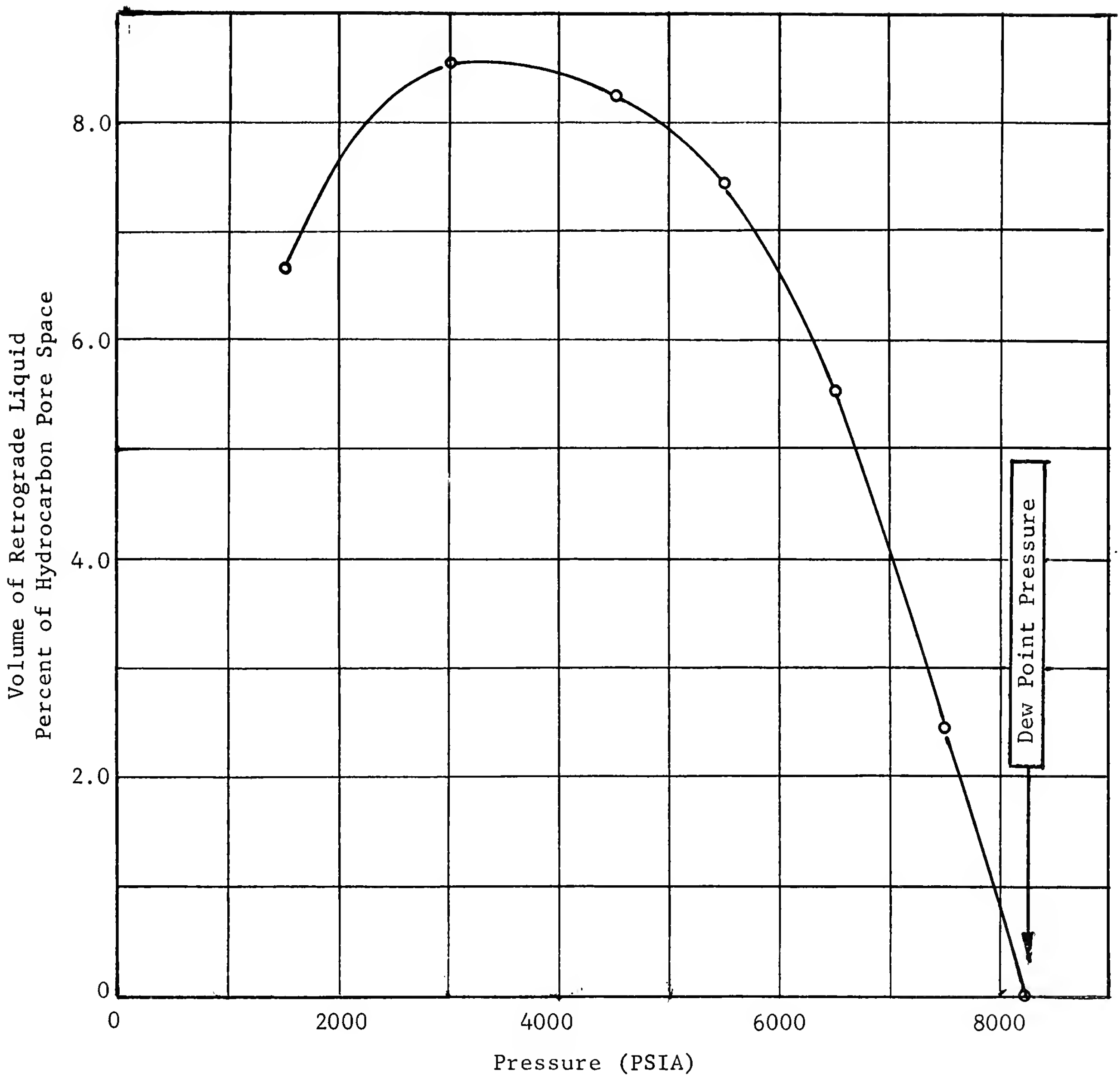
VOLUME OF WELL STREAM PRODUCED

DURING DEPLETION @ 240°F



RETROGRADE CONDENSATION DURING

DEPLETION @ 240°F

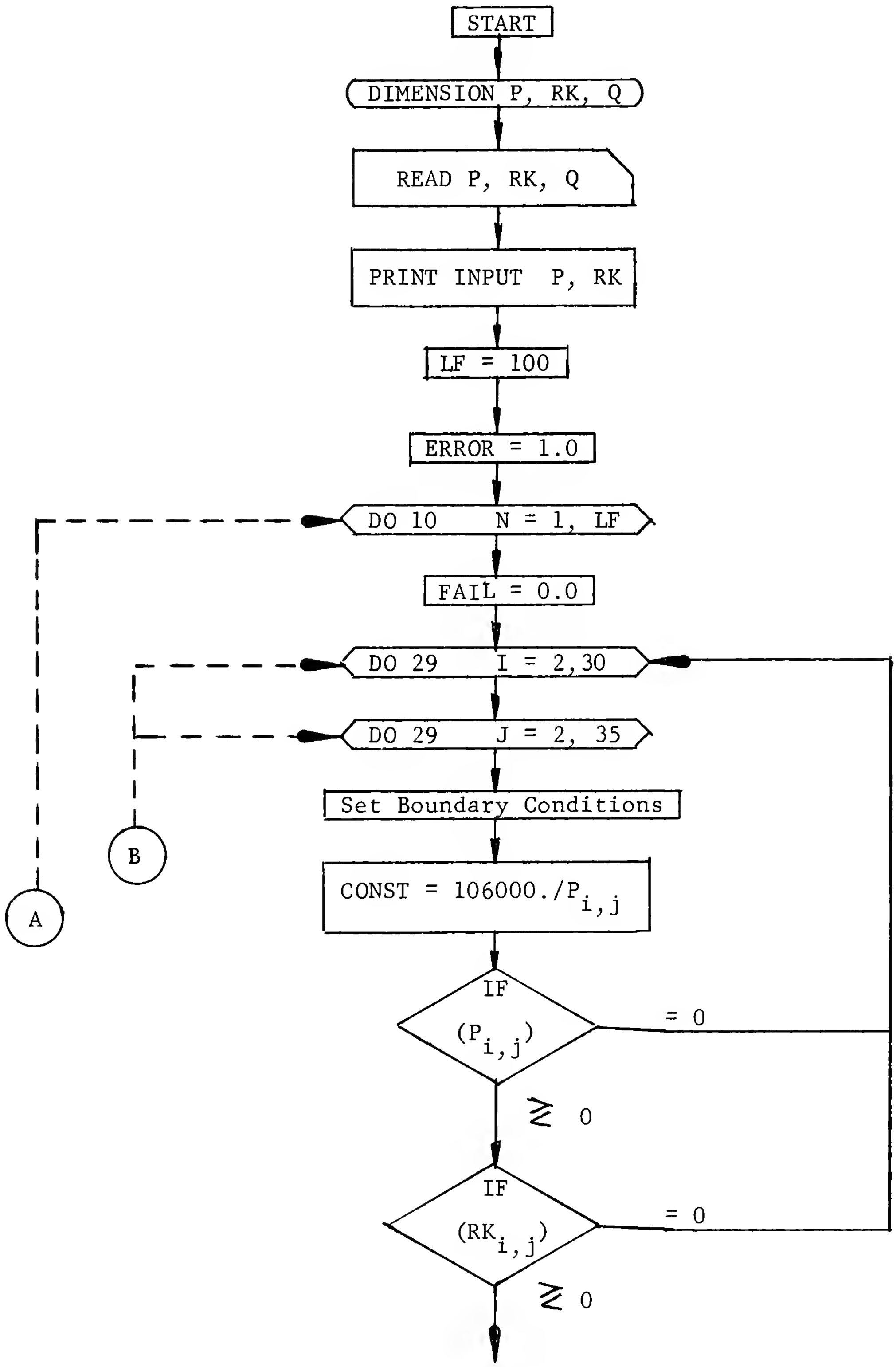


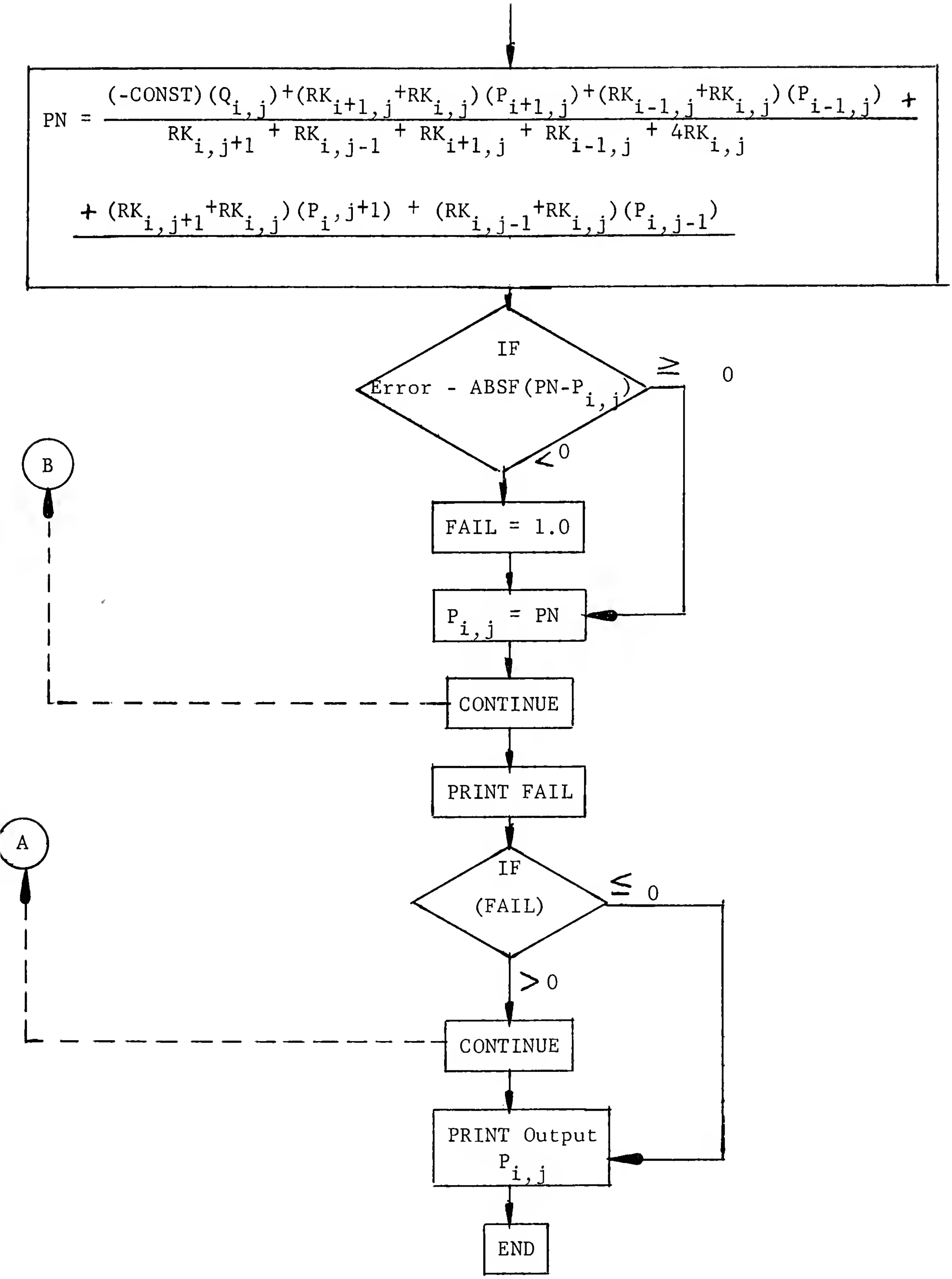
APPENDIX III

VOLUMETRIC SWEEP-OUT PREDICTION

POTENTIAL DISTRIBUTION PROGRAM

PROGRAM POTMAP




$$PN = \frac{(-CONST)(Q_{i,j})+(RK_{i+1,j}+RK_{i,j})(P_{i+1,j})+(RK_{i-1,j}+RK_{i,j})(P_{i-1,j}) + (RK_{i,j+1}+RK_{i,j})(P_{i},j+1) + (RK_{i,j-1}+RK_{i,j})(P_{i,j-1})}{RK_{i,j+1} + RK_{i,j-1} + RK_{i+1,j} + RK_{i-1,j} + 4RK_{i,j}}$$
IF
Error - ABSF(PN-$P_{i,j}$)
≥ 0
< 0
B
FAIL = 1.0
$P_{i,j}$ = PN
CONTINUE
PRINT FAIL
A
IF
(FAIL)
≤ 0
> 0
CONTINUE
PRINT Output
$P_{i,j}$
END

```
      PROGRAM POTMAP
      DIMENSION P(33,38),RK(33,38),Q(33,38)
      DO 40 I=1,31
   40 READ  62, (P(I,J),J=1,12)
      DO 42 I=1,31
   42 READ  62 , (P(I,J),J=13,24)
      DO 63 I=1,31
   63 READ  62,(P(I,J), J=25,36)
      DO 46 I=1,31
   46 READ  41, (Q(I,J)               ,J=1,18)
      DO 48 I=1,31
   48 READ  41, (Q(I,J),J=19,36)
      DO 43 I=1,31
   43 READ  49, (RK(I,J), J=1,12)
      DO 45 I=1,31
   45 READ  49, (RK(I,J),J=13,24)
      DO 61 I=1,31
   61 READ  49,(RK(I,J), J=25,36)
      PRINT 8
    8 FORMAT (1H1)
      DO  1 I=1,31
    1 PRINT 31, (P(I,J),J=1,18)
      PRINT 8
      DO  2 I=1,31
    2 PRINT 31, (P(I,J),J=19,36)
      PRINT 8
      DO  3 I=1,31
   3  PRINT 13,(RK(I,J),J=1,18 )
      PRINT 8
      DO  4 I=1,31
   4  PRINT 13,(RK(I,J),J=19,36)
   13 FORMAT (1X,18F5.2//)
      LF = 200
      ERROR = 1.0
      DO 10 N= 1,LF
      FAIL = 0.0
   12 DO 29 I=2,30
      DO 29 J=2,35
      DO 15 K=1,13
   15 P(10,K)=P(11,K)
      P(10,14) = P(11,15)
      P(9,14) = P(9,15)
      P(8,14) = P(8,15)
      DO 19 K= 15,19
   19 P(7,K) = P(8,K)
      P(7,20) = P(8,21)
      P(6,20) = P(6,21)
      P(5,20) = P(6,21)
      P(5,22)=P(6,22)
      P(5,23)=P(6,23)
      P(5,21) = P(6,21)
      P(5,24)=P(6,24)
      P(5,25) = P(6,26)
      P(4,25) = P(4,26)
      P(3,25) = P(3,26)
      P(2,25) = P(3,26)
```

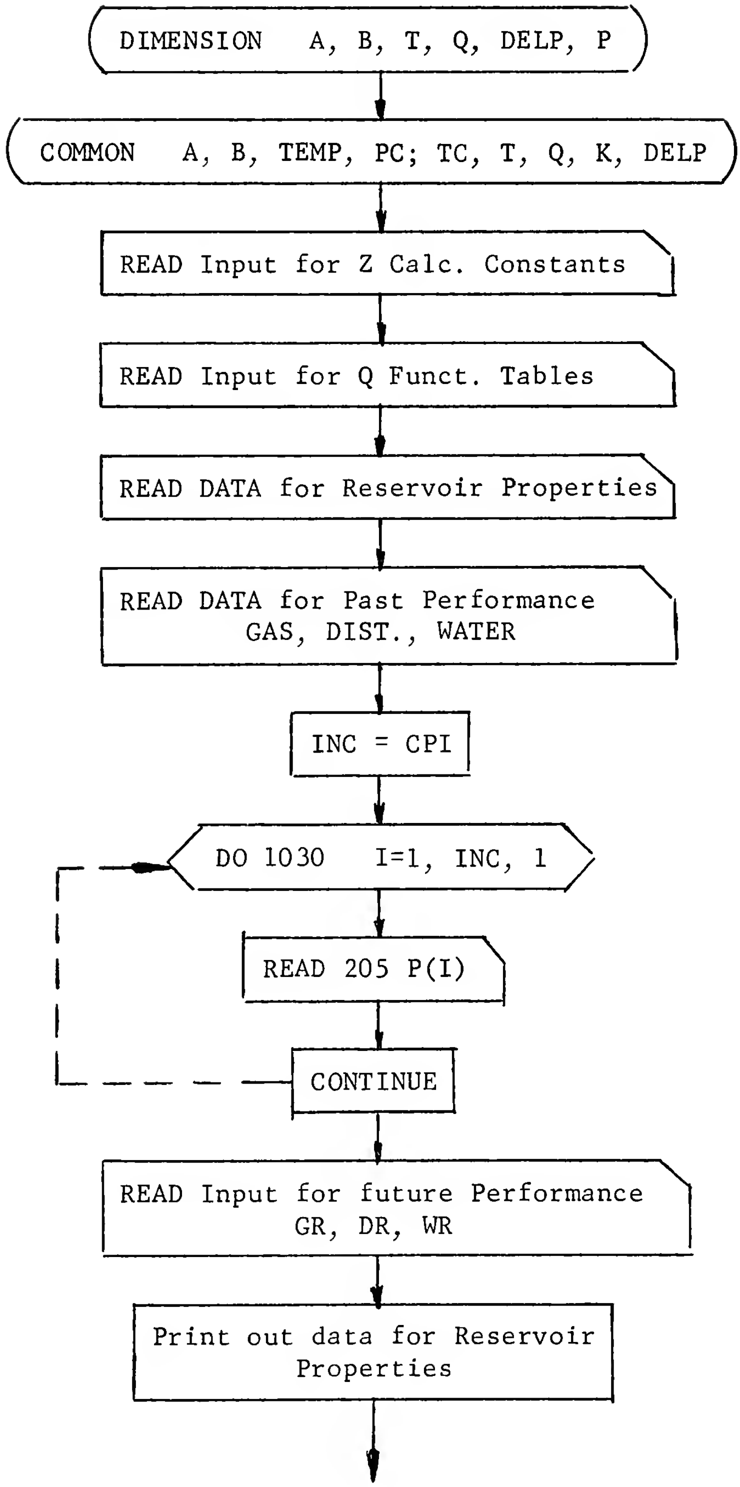
```
      P(2,26) = P(3,26)
      P(2,27) = P(3,27)
      P(2,28) = P(3,28)
      P(2,29) = P(3,30)
      P(1,29)=P(1,30)
      DO 18 K= 1,17
   18 P(30,K)=P(29,K)
      P(29,18)=P(29,17)
      P(30,18) = P(29,17)
      P(28,18) = P(28,17)
      P(27,18) = P(26,17)
      DO 16 K=19,26
   16 P(27,K) = P(26,K)
      P(27,27) = P(26,26)
      P(26,27) = P(26,26)
      P(25,27) = P(25,26)
      P(24,27) = P(23,26)
      DO 17 K=27,36
   17 P(24,K) = P(23,K)
      CONST = 106000./P(I,J)
      IF (P(I,J)) 51,29,51
   51 IF (RK(I,J))52,29,52
   520PN=(-CONST   *Q(I,J)+ (RK(I+1,J)+RK(I,J))*P(I+1,J)+(RK(I-1,J)+RK
     1(I,J))*P(I-1,J)+(RK(I,J+1)+RK(I,J))*P(I,J+1)+(RK(I,J-1)+RK(I,J))*
     2P(I,J-1))       / (RK(I+1,J)+RK(I-1,J)+RK(I,J+1)+RK(I,J-1)+4.*
     3RK(I,J))
      IF (ERROR-ABSF(PN-P(I,J))) 26,27,27
   26 FAIL = 1.0
   27 P(I,J) = PN
   29 CONTINUE
      PRINT 31, FAIL
      IF (FAIL) 33,33,10
   10 CONTINUE
      PRINT 8
   33 DO 30 I=1,31
   30 PRINT 31, (P(I,J),J=1,18)
   31 FORMAT (1X,18F5.0//)
      PRINT 8
      DO 32 I=1,31
   32 PRINT 31, (P(I,J),J=19,36)
   62 FORMAT (12F6.0)
   49 FORMAT(12F6.2)
   41 FORMAT (18F4.0)
   44 FORMAT (18F4.3)
      END
         END       POTMAP
```

APPENDIX IV

FUTURE PERFORMANCE PREDICTION

FUTURE PREDICTION PROGRAM

PROGRAM PREDICT



Print out Past Production Data

$S = P_1$

Calculate Z

$C = .00514590\ (\text{Temp})$

$Bg_i = (C)\left(\frac{Z}{S}\right)$

$t_D = \frac{(1858064)(AK)(\text{Time})}{(\mu)(\emptyset)(R_b)^2}$

$GRB = (G)(Bg_i)$

$FF = \frac{1 - Sg_r - Sw_c}{Sg_i}$

$FLOOD = (GRB)(FF)$

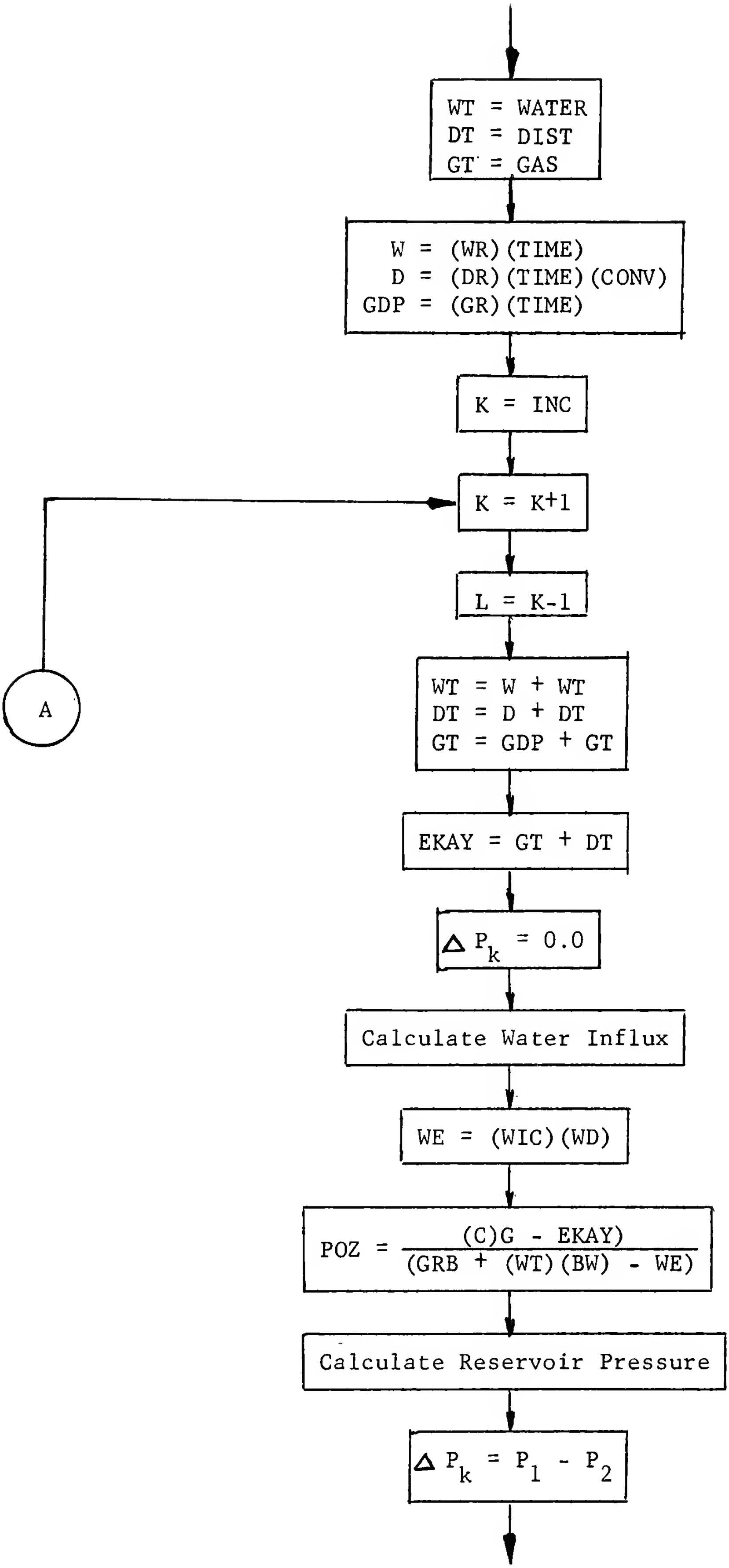
Print out original Conditions

$\Delta P_1 = 0$

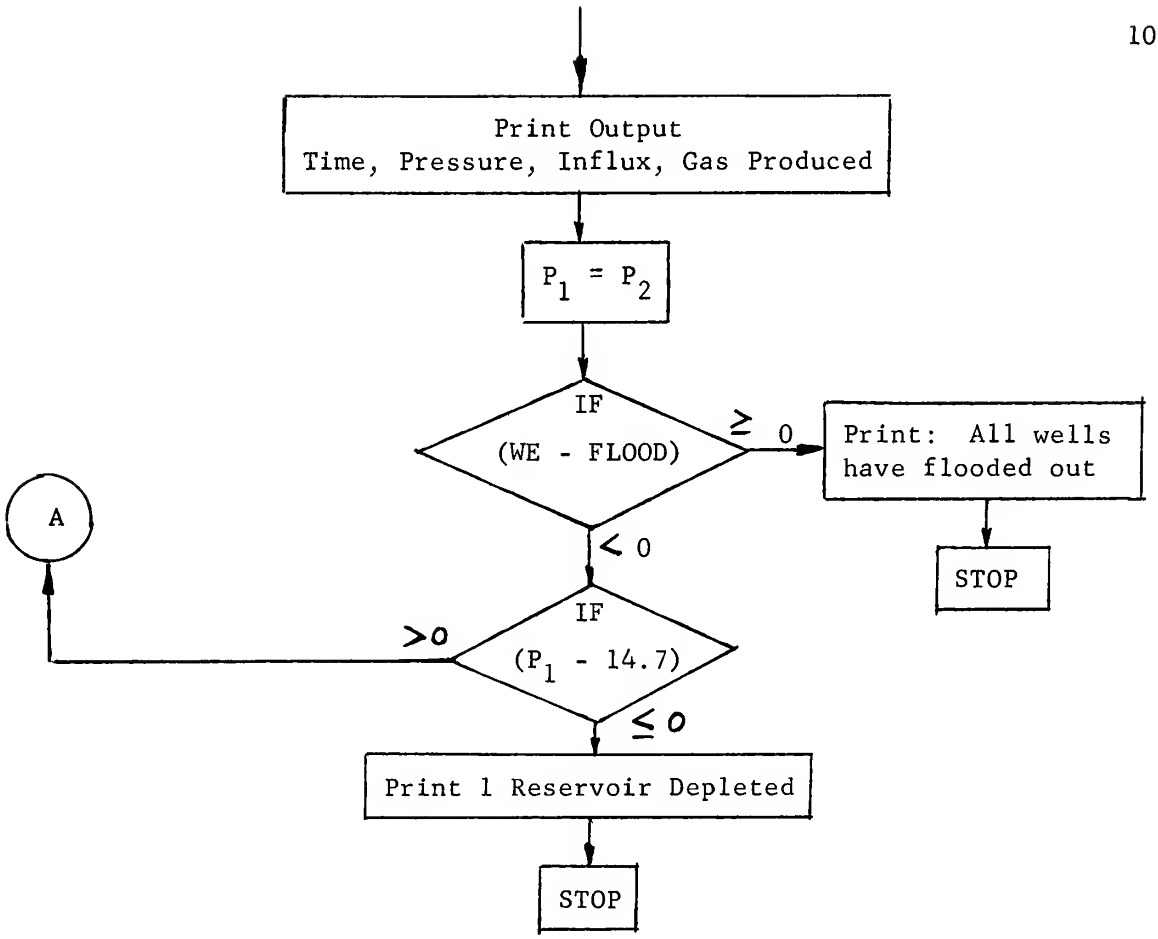
DO 2 I=2, INC, 1

$\Delta P_i = P_{i-1} - P_i$

$P_1 = P_{INC}$

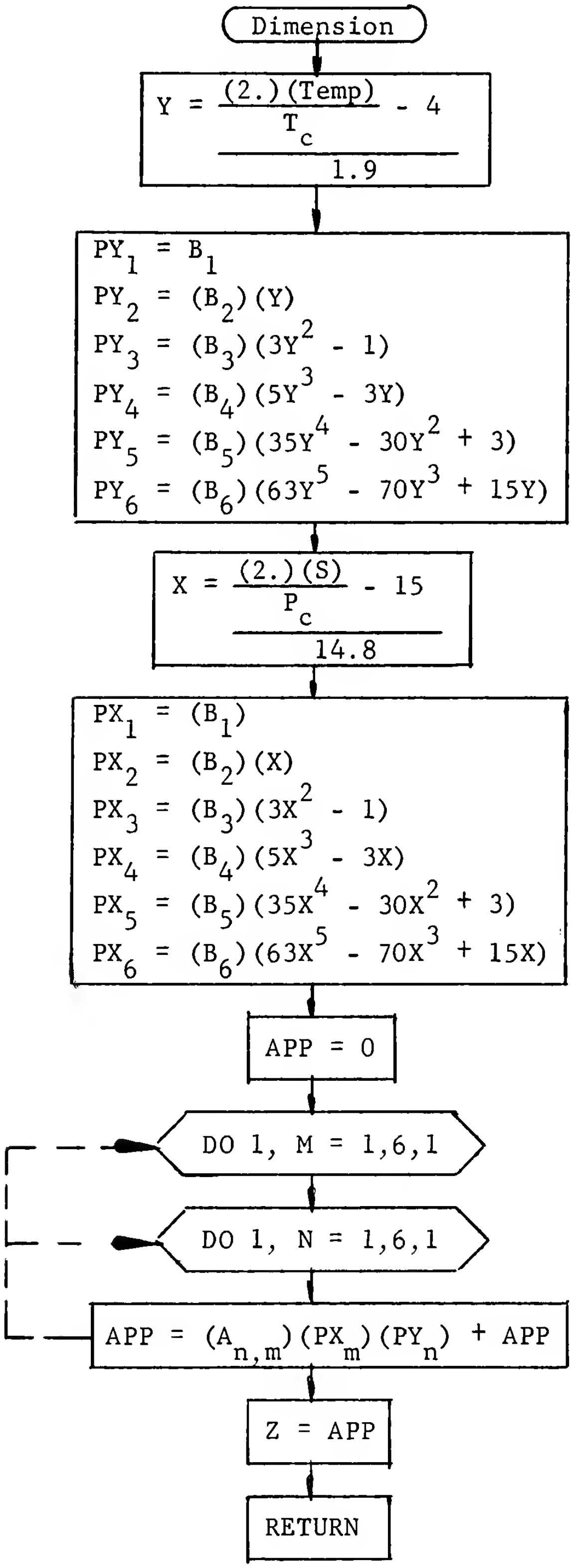


WT = WATER
DT = DIST
GT = GAS
W = (WR)(TIME)
D = (DR)(TIME)(CONV)
GDP = (GR)(TIME)
K = INC
K = K+1
L = K-1
A
WT = W + WT
DT = D + DT
GT = GDP + GT
EKAY = GT + DT
$\Delta P_k = 0.0$
Calculate Water Influx
WE = (WIC)(WD)
$POZ = \frac{(C)G - EKAY)}{(GRB + (WT)(BW) - WE)}$
Calculate Reservoir Pressure
$\Delta P_k = P_1 - P_2$


Print Output
Time, Pressure, Influx, Gas Produced
P1 = P2
IF
(WE - FLOOD)
≥ 0
Print: All wells have flooded out
STOP
< 0
A
>0
IF
(P1 - 14.7)
≤ 0
Print 1 Reservoir Depleted
STOP

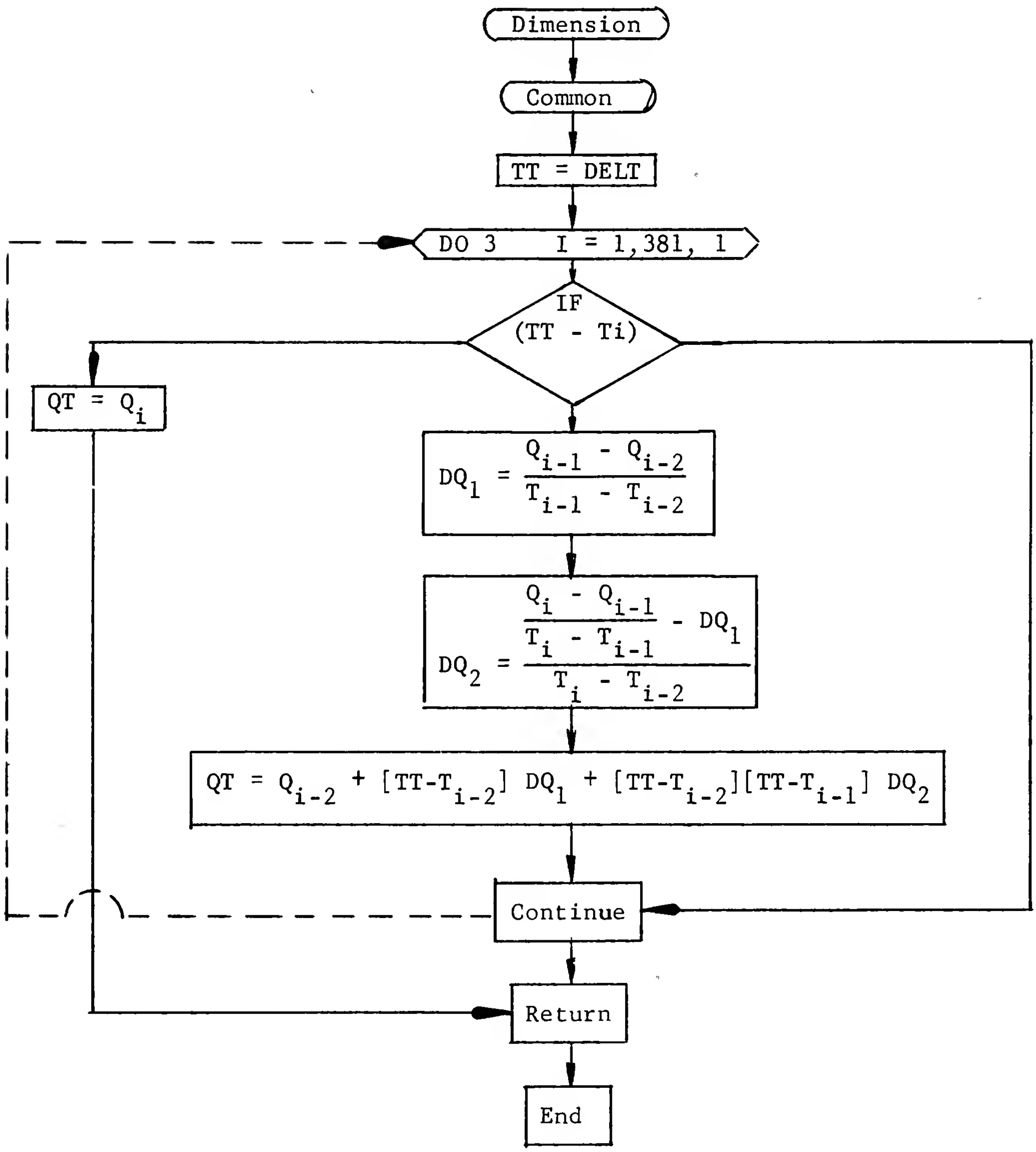
CALCULATION OF GAS DEVIATION FACTOR

Subroutine Z CALC (S,Z)



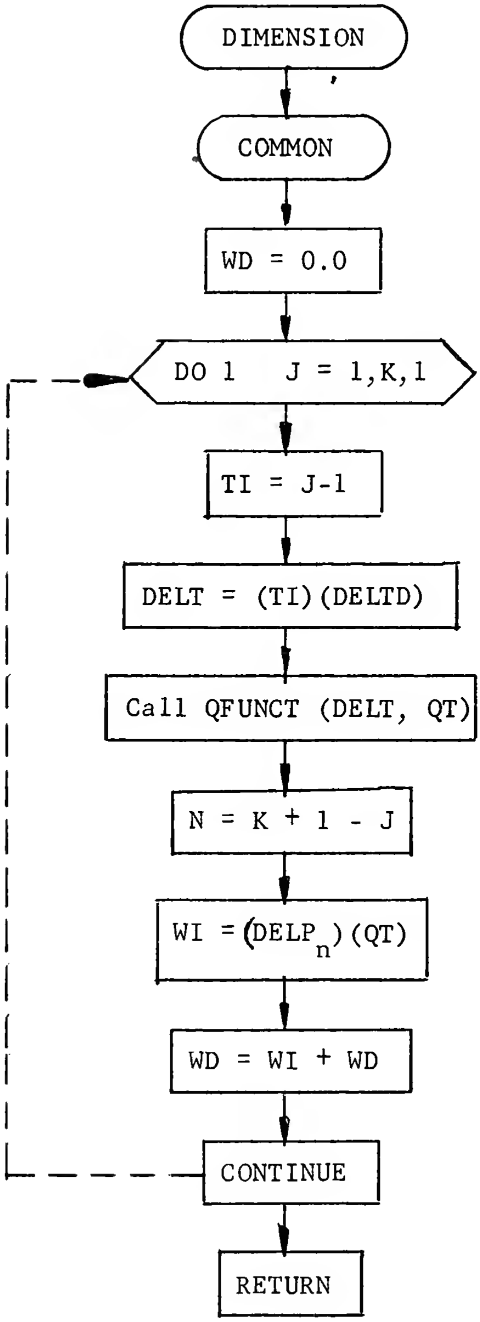
CALCULATION OF DIMENSIONLESS WATER INFLUX

Subroutine QFUNCT (DELT, QT)



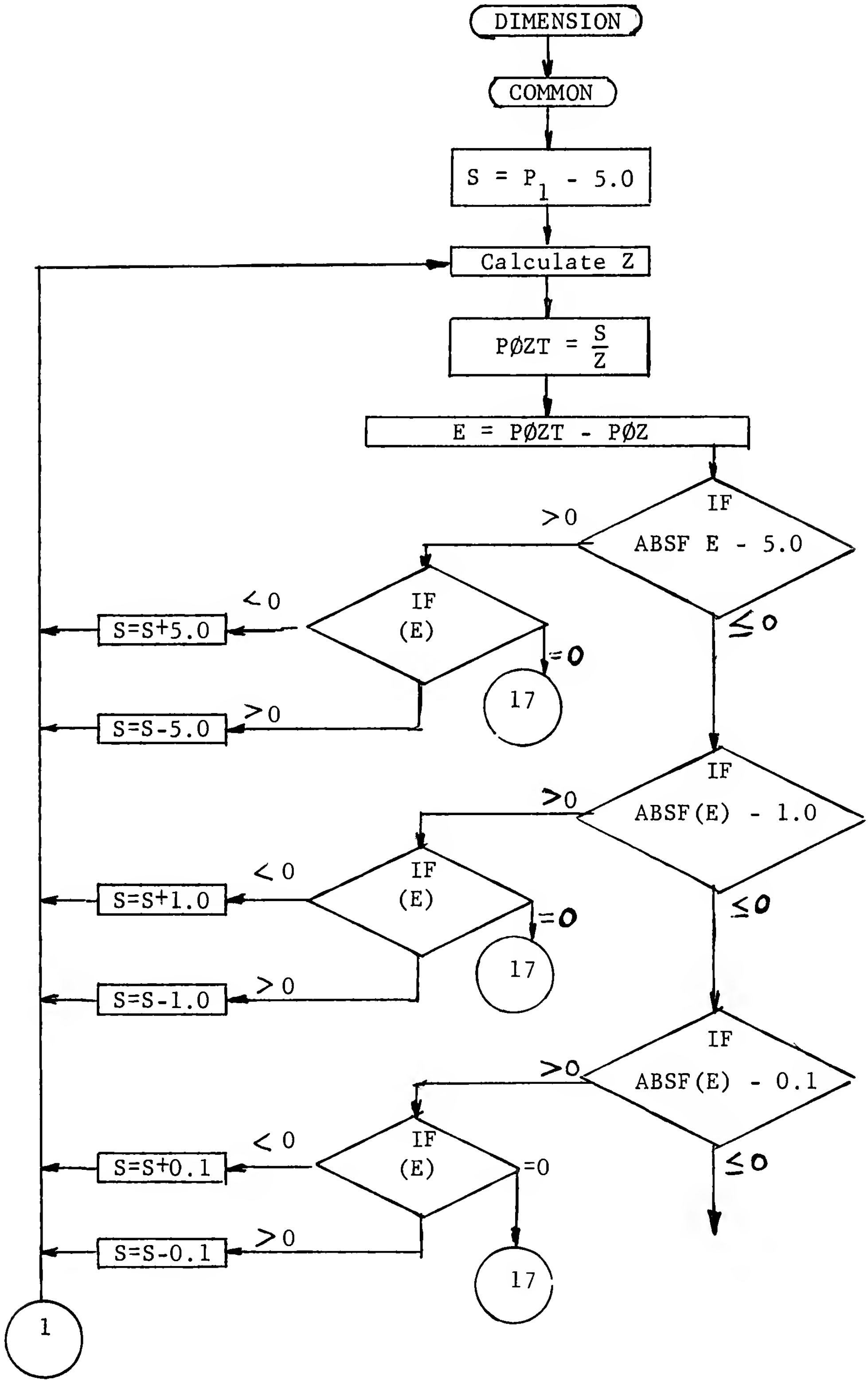
WATER INFLUX CONDITION

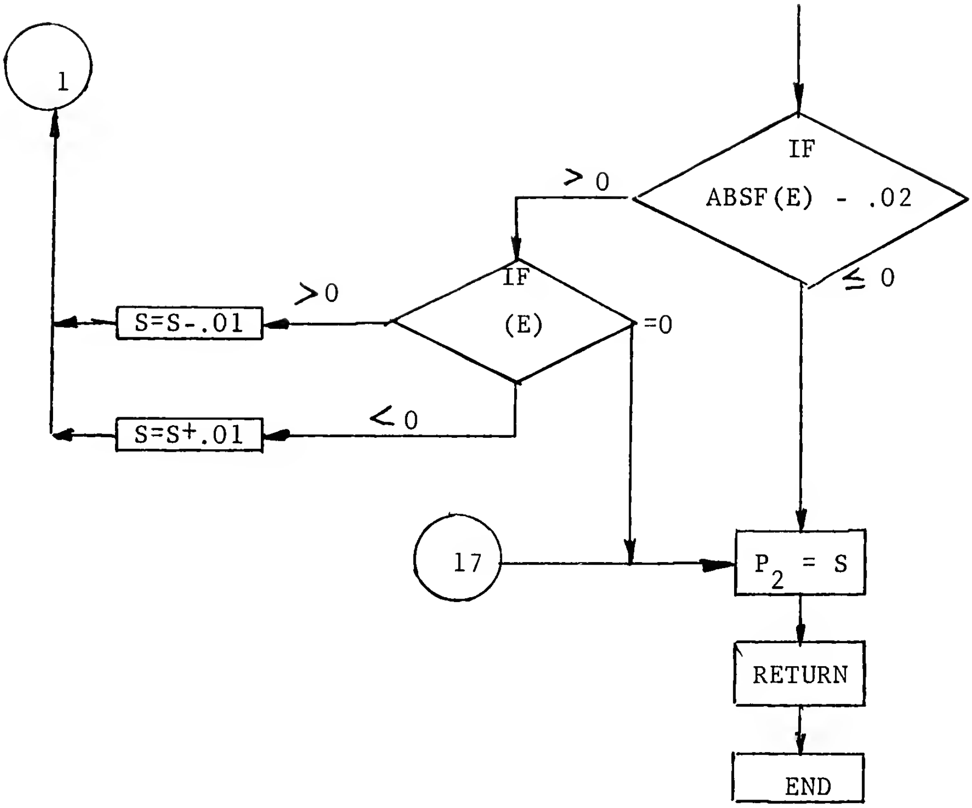
Subroutine INFLUX (DELTD,WD)



PRESSURE CALCULATION

SUBROUTINE PRESS (P_1 POZ, P_2)




1
IF
ABSF(E) - .02
> 0
≤ 0
IF
(E)
> 0
= 0
< 0
S=S-.01
S=S+.01
17
P2 = S
RETURN
END

```
      PROGRAM PREDICT
      DIMENSION A(6,6),B(6),T(471),Q(471),DELP(999),P(40)
      COMMON A,B,TEMP,PC,TC,T,Q,K,DELP
      PRINT 800
  800 FORMAT(1H1)
      PRINT 101
  101 FORMAT(48H RESERVOIR COMPUTER PROJECT---FUTURE PERFORMANCE,//)
      PRINT 102
  102 FORMAT(19H RESERVOIR DATA FOR,/)
C     DATA INPUT FOR SUBROUTINE ZCALC CONSTANTS
      DO 1000 J=1,6,1
      DO 1000 I=1,6,1
      READ 200,A(I,J)
  200 FORMAT(13X,F14.11)
 1000 CONTINUE
      DO 1010 I=1,6,1
      READ 201,B(I)
  201 FORMAT(F14.11)
 1010 CONTINUE
C     DATA INPUT FOR SUBROUTINE QFUNCT TABLE
      DO 1020 I=1,471,3
      READ 202,T(I),Q(I),T(I+1),Q(I+1),T(I+2),Q(I+2)
  202 FORMAT(F12.2,F12.3,F12.2,F12.3,F12.2,F12.3)
 1020 CONTINUE
C     DATA INPUT FOR RESERVOIR PROPERTIES
      READ 203,AIWEL
      READ 203,CONV
      READ 203,RI
      READ 203,DEPTH
      READ 203,TEMP
      READ 203,SGI
      READ 203,O
      READ 203,AH
      READ 203,SG
      READ 203,U
      READ 203,AK
      READ 203,TIME
      READ 203,SGR
      READ 203,SWC
      READ 203,PI
      READ 203,PC
      READ 203,TC
      READ 203,BW
      READ 203,CPI
      READ 203,WIC
      READ 203,G
  203 FORMAT(F16.7)
C     DATA INPUT FOR PAST PERFORMANCE
      READ 204,GAS,DIST,WATER
  204 FORMAT(E16.8,4X,E16.8,4X,E16.8)
      INC=CPI
      DO 1030 I=1,INC,1
      READ 205,P(I)
  205 FORMAT(F10.3)
 1030 CONTINUE
C     DATA INPUT FOR FUTURE PERFORMANCE
```

```
    1 READ 700,KK
  700 FORMAT(I3)
      READ 203, GR
      READ 203, DR
      READ 203, WR
C     DATA PRINT OUT FOR RESERVOIR PROPERTIES
      PRINT 300,INC
  300 FORMAT(45H INC,CURRENT NUMBER OF PRODUCTION INCREMENTS=,I4)
      PRINT 301,AIWEL
  301 FORMAT(48H MAX. NUMBER OF PRODUCING WELLS AT ANY ONE TIME=,F6.1)
      PRINT 302,BW
  302 FORMAT(50H BW,FORMATION VOLUME FACTOR FOR WATER IN BBLS/STB=,F6.3)
      PRINT 303,CONV
  303 FORMAT(44H CONV,SCF OF VAPOR PER BARREL OF DISTILLATE=,F7.1)
      PRINT 304,RI
  304 FORMAT(48H RI,RADIUS TO INITIAL EDGE OF RESERVOIR IN FEET=,F8.1)
      PRINT 305,DEPTH
  305 FORMAT(34H DEPTH,DEPTH OF RESERVOIR IN FEET=,F8.1)
      PRINT 306,TEMP
  306 FORMAT(50H TEMP,TEMPERATURE OF RESERVOIR IN DEGREES RANKINE=,F7.1)
      PRINT 307,PC
  307 FORMAT(36H PC,PSEUDOCRITICAL PRESSURE IN PSIA=,F6.1)
      PRINT 308,TC
  308 FORMAT(50H TC,PSEUDOCRITICAL TEMPERATURE IN DEGREES RANKINE=,F6.1)
      PRINT 309,SGI
  309 FORMAT(40H SGI,INITIAL GAS SATURATION AS FRACTION=,F5.3)
      PRINT 310,O
  310 FORMAT(24H O,POROSITY AS FRACTION=,F5.3)
      PRINT 311,AH
  311 FORMAT(43H AH,AVERAGE THICKNESS OF RESERVOIR IN FEET=,F6.1)
      PRINT 312,SG
  312 FORMAT(44H SG,SPECIFIC GRAVITY OF GAS RELATIVE TO AIR=,F7.4)
      PRINT 313,U
  313 FORMAT(46H U,VISCOSITY OF RESERVOIR WATER IN CENTIPOISE=,F6.3)
      PRINT 314,AK
  314 FORMAT(47H AK,WATER PERMEABILITY OF RESERVOIR IN DARCIES=,F7.4)
      PRINT 315,TIME
  315 FORMAT(33H TIME,TIME INTERVAL USED IN DAYS=,F7.2)
      PRINT 316,SGR
  316 FORMAT(41H SGR,RESIDUAL GAS SATURATION AS FRACTION=,F5.3)
      PRINT 317,SWC
  317 FORMAT(42H SWC,CONNATE WATER SATURATION AS FRACTION=,F5.3)
      PRINT 318,WIC
  318 FORMAT(45H WIC,WATER INFLUX CONSTANT IN BBLS. PER PSIA=,F10.3,//)
C     DATA PRINT OUT FOR RESERVOIR PRODUCTION
      PRINT 103
  103 FORMAT(55H RESERVOIR PRODUCTION FOR FUTURE PERFORMANCE PREDICTION)
      PRINT 104
  104 FORMAT(1H )
      PRINT 319,GR
  319 FORMAT(41H AVERAGE DAILY DRY GAS PRODUCTION IN SCF=,F16.1)
      PRINT 320,DR
  320 FORMAT(44H AVERAGE DAILY DISTILLATE PRODUCTION IN STB=,F16.1)
      PRINT 321,WR
  321 FORMAT(39H AVERAGE DAILY WATER PRODUCTION IN STB=,F16.1,//)
C     MAIN BODY OF PROGRAM
```

```
      S=P(1)
      CALL ZCALC(S,Z)
      C=0.00514590*TEMP
      BGI=C*Z/S
      DELTD=1858064.0*AK*TIME/(U*O*RI*RI)
      GRB=G*BGI
      FF=(1.0-SGR-SWC)/SGI
      FLOOD=GRB*FF
      PRINT 105
  105 FORMAT(19H INITIAL CONDITIONS,/)
      PRINT 322,PI
  322 FORMAT(26H INITIAL PRESSURE IN PSIA=,F8.2)
      PRINT 323,G
  323 FORMAT(29H INITIAL GAS IN PLACE IN SCF=,E16.8)
      PRINT 400,FLOOD
  400 FORMAT(47H MAXIMUM FLOODABLE RESERVOIR VOLUME IN BARRELS=,E16.8)
      PRINT 401,Z
  401 FORMAT(36H INITIAL GAS COMPRESSIBILITY FACTOR=,E16.8,//)
      PRINT 106
  106 FORMAT(1H ,/,18H FUTURE PREDICTION,/)
      PRINT 107
  107 FORMAT(15H TIME  PRESSURE,9X,2HWE,16X,3HGPW,8X,7HDELTA P)
      DELP(1)=0.0
      DO 2 I=2,INC,1
    2 DELP(I)=P(I-1)-P(I)
      P1=P(INC)
      WT=WATER
      DT=DIST
      GT=GAS
      W=WR*TIME
      D=DR*TIME*CONV
      GDP=GR*TIME
      K=INC
    3 K=K+1
      L=K-1
      WT=W+WT
      DT=D+DT
      GT=GDP+GT
      EKAY=GT+DT
      DELP(K)=0.0
      CALL INFLUX(DELTD,WD)
      WE=WIC*WD
      POZ=C*(G-EKAY)/(GRB+WT*BW-WE)
      CALL PRESS(P1,POZ,P2)
      DELP(K)=P1-P2
      PRINT 402,L,P2,WE,EKAY,DELP(K)
  402 FORMAT(I5,2X,F8.2,2X,E16.8,2X,E16.8,2X,F8.2)
      P1=P2
      IF(WE-FLOOD) 8,4,4
    4 PRINT 108
  108 FORMAT(1H ,/,27H ALL WELLS HAVE FLOODED OUT,/////)
      CONTINUE
    5 IF(KK-1) 6,6,7
    6 CONTINUE
    7 GO TO 1
    8 IF(P1-14.7) 10,10,9
```

```
  9 GO TO 3
 10 PRINT 109
109 FORMAT(1H ,/,19H RESERVOIR DEPLETED,/////)
    CONTINUE
    GO TO 5
       END
```

```
      SUBROUTINE ZCALC(S,Z)
      DIMENSION A(6,6),B(6),T(471),Q(471),DELP(999),P(40)
      DIMENSION PX(6),PY(6)
      COMMON A,B,TEMP,PC,TC,T,Q,K,DELP
      Y=((2.0*TEMP/TC)-4.0)/1.9
      PY(1)=B(1)
      PY(2)=B(2)*Y
      PY(3)=B(3)*((3.0*Y*Y)-1.0)
      PY(4)=B(4)*((5.0*Y*Y)-3.0)*Y
      PY(5)=B(5)*(((35.0*Y*Y)-30.0)*Y*Y+3.0)
      PY(6)=B(6)*((((63.0*Y*Y)-70.0)*Y*Y)+15.0)*Y
      X=((2.0*S/PC)-15.0)/14.8
      PX(1)=B(1)
      PX(2)=B(2)*X
      PX(3)=B(3)*((3.0*X*X)-1.0)
      PX(4)=B(4)*((5.0*X*X)-3.0)*X
      PX(5)=B(5)*((((35.0*X*X)-30.0)*X*X)+3.0)
      PX(6)=B(6)*((((63.0*X*X)-70.0)*X*X)+15.0)*X
      APP=0.0
      DO 1 M=1,6,1
      DO 1 N=1,6,1
    1 APP=(A(N,M)*PX(M)*PY(N))+APP
      Z=APP
      RETURN
      END
```

```
      SUBROUTINE QFUNCT(DELT,QT)
      DIMENSION A(6,6),B(6),T(471),Q(471),DELP(999),P(40)
      COMMON A,B,TEMP,PC,TC,T,Q,K,DELP
      TT=DELT
      DO 3 I=1,471,1
      IF(TT-T(I)) 1,2,3
    1 DQ1=(Q(I-1)-Q(I-2))/(T(I-1)-T(I-2))
      DQ2=((Q(I)-Q(I-1))/(T(I)-T(I-1))-DQ1)/(T(I)-T(I-2))
      QT=Q(I-2)+(TT-T(I-2))*DQ1+(TT-T(I-2))*(TT-T(I-1))*DQ2
      GO TO 4
    2 QT=Q(I)
      GO TO 4
    3 CONTINUE
    4 RETURN
      END
```

```
      SUBROUTINE INFLUX(DELTD,WD)
      DIMENSION A(6,6),B(6),T(471),Q(471),DELP(999),P(40)
      COMMON A,B,TEMP,PC,TC,T,Q,K,DELP
      WD=0.0
      DO 1 J=1,K,1
      TI=J-1
      DELT=TI*DELTD
      CALL QFUNCT(DELT,QT)
      N=K+1-J
      WI=DELP(N)*QT
    1 WD=WI+WD
      CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PRESS(P1,POZ,P2)
      DIMENSION A(6,6),B(6),T(471),Q(471),DELP(999),P(40)
      COMMON A,B,TEMP,PC,TC,T,Q,K,DELP
      S=P1-5.0
    1 CALL ZCALC(S,Z)
      POZT=S/Z
      E=POZT-POZ
      IF(ABSF(E)-5.0) 5,5,2
    2 IF(E) 4,17,3
    3 S=S-5.0
      GO TO 1
    4 S=S+5.0
      GO TO 1
    5 IF(ABSF(E)-1.0) 9,9,6
    6 IF(E) 8,17,7
    7 S=S-1.0
      GO TO 1
    8 S=S+1.0
      GO TO 1
    9 IF(ABSF(E)-0.1) 13,13,10
   10 IF(E) 12,17,11
   11 S=S-0.1
      GO TO 1
   12 S=S+0.1
      GO TO 1
   13 IF(ABSF(E)-0.02) 17,17,14
   14 IF(E) 16,17,15
   15 S=S-0.01
      GO TO 1
   16 S=S+0.01
      GO TO 1
   17 P2=S
      RETURN
      END
         END        PREDICT
```

```
C     DATA INPUT FOR SUBROUTINE ZCALC CONSTANTS

               2.1433504
               0.083176184
              -0.021467042
              -0.00087140318
               0.0042846283
              -0.0016595343
               0.33123524
              -0.13403614
               0.066880961
              -0.027174261
               0.0088512291
              -0.0021520929
               0.10572871
              -0.050393654
               0.0050924798
               0.010551336
              -0.0073181933
               0.0026959963
              -0.052184040
               0.044312146
              -0.019329465
               0.0058972516
               0.0015366676
              -0.0028326809
               0.019703980
              -0.026383354
               0.019262143
              -0.011535390
               0.0042910089
              -0.00081302526
              -0.0053095900
               0.0089178330
              -0.010894821
               0.009559389
              -0.0060114017
               0.0031175170
0.7071068
1.224745
0.7905695
0.9354145
0.265165
0.293151

C     DATA INPUT FOR SUBROUTINE QFUNCT TABLE

    00000000    00000000    00000001    00000112    00000005    00000278
    00000010    00000404    00000015    00000520    00000020    00000606
    00000025    00000689    00000030    00000758    00000040    00000898
    00000050    00001020    00000060    00001140    00000070    00001251
    00000080    00001359    00000090    00001469    00000100    00001569
    00000200    00002447    00000300    00003202    00000400    00003893
```

00000500	00004539	00000600	00005153	00000700	00005743
00000800	00006314	00000900	00006869	00001000	00007411
00001100	00007940	00001200	00008457	00001300	00008964
00001400	00009461	00001500	00009949	00001600	00010434
00001700	00010913	00001800	00011386	00001900	00011855
00002000	00012319	00002100	00012778	00002200	00013233
00002300	00013684	00002400	00014131	00002500	00014573
00002600	00015013	00002700	00015450	00002800	00015883
00002900	00016313	00003000	00016742	00003100	00017167
00003200	00017590	00003300	00018011	00003400	00018429
00003500	00018845	00003600	00019259	00003700	00019671
00003800	00020080	00003900	00020488	00004000	00020894
00004100	00021298	00004200	00021701	00004300	00022101
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00039000	00131972	00039500	00133391	00040000	00134808
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00042000	00140453	00042500	00141859	00043000	00143262
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00114000	00328480	00115000	00330958	00116000	00333433
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00127000	00360496	00127500	00361720	00128000	00362942
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00134000	00377572	00135000	00380003	00136000	00382432
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00139000	00389705	00140000	00392125	00141000	00394543
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00144000	00401786	00145000	00404197	00146000	00406606
00147000	00409013	00147500	00410214	00148000	00411418
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00162500	00446077	00165000	00452016	00167500	00457945
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00200000	00534145	00202500	00539945	00205000	00545737
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00245000	00637437	00247500	00643113	00250000	00648781

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00285000	00727449	00290000	00738598	00295000	00749725
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00345000	00859974	00350000	00870903	00355000	00881816
00360000	00892712	00365000	00903594	00370000	00914459
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00390000	00957773	00395000	00968566	00400000	00979344
00405000	00990108	00410000	01000858	00415000	01011595
00420000	01022318	00425000	01033028	00430000	01043724
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00480000	01150012	00485000	01160574	00490000	01171125
00495000	01181666	00500000	01192198	00510000	01213222
00520000	01234203	00530000	01255141	00540000	01276037
00550000	01296893	00560000	01317709	00570000	01338486
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00670000	01544305	00680000	01564706	00690000	01585077
00700000	01605418	00710000	01625729	00720000	01646011
00730000	01666265	00740000	01686490	00750000	01706688
00760000	01726859	00770000	01747002	00780000	01767120
00790000	01787212	00800000	01807278	00810000	01827319
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00880000	01966943	00890000	01986796	00900000	02006628
00910000	02026438	00920000	02046227	00930000	02065996
00940000	02085744	00950000	02105473	00960000	02125184
00970000	02144878	00980000	02164555	00990000	02184216
01000000	02203861	01250000	02688967	01500000	03164780
01750000	03633368	02000000	04095800	02500000	05005726
03000000	05899508	03500000	06780247	04000000	07650096
05000000	09363099	06000000	11047299	07000000	12708358
07500000	13531457	08000000	14350121	09000000	15975389
10000000	17586284	12500000	21560732	15000000	25380000

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C      DATA INPUT FOR RESERVOIR PROPERTIES

2.0
768.0
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11450.
690.
.80
.28
64.4
.7975
.30
.050
180.
.30
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0.15
8838.
662.26
387.48
1.03
7.0
7.52757
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  2.07907540E+10         1.54221800E+06         8.67600000E+03
8838.
8764.
8657.
8509.
8364.
8219.
8100.
  9
25000000.
1250.
30.
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RESERVOIR COMPUTER PROJECT---FUTURE PERFORMANCE

RESERVOIR DATA FOR

INC,CURRENT NUMBER OF PRODUCTION INCREMENTS= 7
MAX. NUMBER OF PRODUCING WELLS AT ANY ONE TIME= 2.0
BW,FORMATION VOLUME FACTOR FOR WATER IN BBLS/STB= 1.030
CONV,SCF OF VAPOR PER BARREL OF DISTILLATE= 768.0
RI,RADIUS TO INITIAL EDGE OF RESERVOIR IN FEET= 2190.0
DEPTH,DEPTH OF RESERVOIR IN FEET= 11450.0
TEMP,TEMPERATURE OF RESERVOIR IN DEGREES RANKINE= 690.0
PC,PSEUDOCRITICAL PRESSURE IN PSIA= 662.3
TC,PSEUDOCRITICAL TEMPERATURE IN DEGREES RANKINE= 387.5
SGI,INITIAL GAS SATURATION AS FRACTION= .800
O,POROSITY AS FRACTION= .280
AH,AVERAGE THICKNESS OF RESERVOIR IN FEET= 64.4
SG,SPECIFIC GRAVITY OF GAS RELATIVE TO AIR= .7975
U,VISCOSITY OF RESERVOIR WATER IN CENTIPOISE= .300
AK,WATER PERMEABILITY OF RESERVOIR IN DARCIES= .0500
TIME,TIME INTERVAL USED IN DAYS= 180.00
SGR,RESIDUAL GAS SATURATION AS FRACTION= .300
SWC,CONNATE WATER SATURATION AS FRACTION= .150
WIC,WATER INFLUX CONSTANT IN BBLS. PER PSIA= 7.528

RESERVOIR PRODUCTION FOR FUTURE PERFORMANCE PREDICTION
AVERAGE DAILY DRY GAS PRODUCTION IN SCF= 25000000.0
AVERAGE DAILY DISTILLATE PRODUCTION IN STB= 1250.0
AVERAGE DAILY WATER PRODUCTION IN STB= 30.0

INITIAL CONDITIONS

INITIAL PRESSURE IN PSIA= 8838.00
INITIAL GAS IN PLACE IN SCF= 6.06898622E 11
MAXIMUM FLOODABLE RESERVOIR VOLUME IN BARRELS= 2.22914288E 08
INITIAL GAS COMPRESSIBILITY FACTOR= 1.32981926E 00

FUTURE PREDICTION

TIME	PRESSURE	WE	GPW	DELTA P
7	8009.66	3.01997662E 05	2.54650962E 10	90.34
8	7870.52	3.92764487E 05	3.01378962E 10	139.14
9	7734.90	4.98711813E 05	3.48106962E 10	135.62
10	7602.48	6.17296089E 05	3.94834962E 10	132.42
11	7473.08	7.47733989E 05	4.41562962E 10	129.40
12	7346.57	8.89432311E 05	4.88290962E 10	126.51
13	7222.84	1.04188907E 06	5.35018962E 10	123.73
14	7101.81	1.20466079E 06	5.81746962E 10	121.03
15	6983.39	1.37735030E 06	6.28474962E 10	118.42
16	6867.53	1.55959584E 06	6.75202962E 10	115.86
17	6754.18	1.75105577E 06	7.21930962E 10	113.35

18	6643.27	1.95140676E 06	7.68658962E 10	110.91
19	6534.76	2.16034859E 06	8.15386962E 10	108.51
20	6428.60	2.37757163E 06	8.62114962E 10	106.16
21	6324.75	2.60283387E 06	9.08842962E 10	103.85
22	6223.15	2.83585730E 06	9.55570962E 10	101.60
23	6123.75	3.07640675E 06	1.00229896E 11	99.40
24	6026.50	3.32422979E 06	1.04902696E 11	97.25
25	5931.35	3.57910580E 06	1.09575496E 11	95.15
26	5838.24	3.84080861E 06	1.14248296E 11	93.11
27	5747.13	4.10910827E 06	1.18921096E 11	91.11
28	5657.94	4.38383777E 06	1.23593896E 11	89.19
29	5570.63	4.66479429E 06	1.28266696E 11	87.31
30	5485.14	4.95179404E 06	1.32939496E 11	85.49
31	5401.40	5.24466308E 06	1.37612296E 11	83.74
32	5319.37	5.54323484E 06	1.42285096E 11	82.03
33	5238.99	5.84734876E 06	1.46957896E 11	80.38
34	5160.19	6.15685365E 06	1.51630696E 11	78.80
35	5082.93	6.47160388E 06	1.56303496E 11	77.26
36	5007.15	6.79146218E 06	1.60976296E 11	75.78
37	4932.79	7.11629632E 06	1.65649096E 11	74.36
38	4859.81	7.44598239E 06	1.70321896E 11	72.98
39	4788.15	7.78039908E 06	1.74994696E 11	71.66
40	4717.76	8.11943332E 06	1.79667496E 11	70.39
41	4648.59	8.46297811E 06	1.84340296E 11	69.17
42	4580.60	8.81092942E 06	1.89013096E 11	67.99
43	4513.74	9.16318972E 06	1.93685896E 11	66.86
44	4447.97	9.51966598E 06	1.98358696E 11	65.77
45	4383.24	9.88026859E 06	2.03031496E 11	64.73
46	4319.51	1.02449144E 07	2.07704296E 11	63.73
47	4256.74	1.06135227E 07	2.12377096E 11	62.77
48	4194.90	1.09860180E 07	2.17049896E 11	61.84
49	4133.94	1.13623269E 07	2.21722696E 11	60.96
50	4073.83	1.17423812E 07	2.26395496E 11	60.11
51	4014.54	1.21261164E 07	2.31068296E 11	59.29
52	3956.03	1.25134699E 07	2.35741096E 11	58.51
53	3898.27	1.29043838E 07	2.40413896E 11	57.76
54	3841.23	1.32988022E 07	2.45086696E 11	57.04
55	3784.88	1.36966727E 07	2.49759496E 11	56.35
56	3729.18	1.40979449E 07	2.54432296E 11	55.70
57	3674.12	1.45025730E 07	2.59105096E 11	55.06
58	3619.67	1.49105112E 07	2.63777896E 11	54.45
59	3565.79	1.53217166E 07	2.68450696E 11	53.88
60	3512.46	1.57361517E 07	2.73123496E 11	53.33
61	3459.66	1.61537783E 07	2.77796296E 11	52.80
62	3407.38	1.65745573E 07	2.82469096E 11	52.28
63	3355.57	1.69984484E 07	2.87141896E 11	51.81
64	3304.23	1.74254188E 07	2.91814696E 11	51.34
65	3253.32	1.78554343E 07	2.96487496E 11	50.91
66	3202.82	1.82884669E 07	3.01160296E 11	50.50
67	3152.74	1.87244912E 07	3.05833096E 11	50.08
68	3103.03	1.91634781E 07	3.10505896E 11	49.71
69	3053.68	1.96054041E 07	3.15178696E 11	49.35
70	3004.67	2.00502457E 07	3.19851496E 11	49.01
71	2955.97	2.04979827E 07	3.24524296E 11	48.70
72	2907.60	2.09485976E 07	3.29197096E 11	48.37
73	2859.50	2.14020682E 07	3.33869896E 11	48.10

74	2811.68	2.18583818E 07	3.38542696E 11	47.82
75	2764.11	2.23175214E 07	3.43215496E 11	47.57
76	2716.78	2.27794740E 07	3.47888296E 11	47.33
77	2669.68	2.32442265E 07	3.52561096E 11	47.10
78	2622.78	2.37117672E 07	3.57233896E 11	46.90
79	2576.07	2.41820867E 07	3.61906696E 11	46.71
80	2529.54	2.46551770E 07	3.66579496E 11	46.53
81	2483.18	2.51310297E 07	3.71252296E 11	46.36
82	2436.96	2.56096366E 07	3.75925096E 11	46.22
83	2390.86	2.60909930E 07	3.80597896E 11	46.10
84	2344.88	2.65750960E 07	3.85270696E 11	45.98
85	2299.05	2.70619420E 07	3.89943496E 11	45.83
86	2253.25	2.75515216E 07	3.94616296E 11	45.80
87	2207.58	2.80438455E 07	3.99289096E 11	45.67
88	2161.95	2.85389026E 07	4.03961896E 11	45.63
89	2116.35	2.90366994E 07	4.08634696E 11	45.60
90	2070.82	2.95372392E 07	4.13307496E 11	45.53
91	2025.29	3.00405193E 07	4.17980296E 11	45.53
92	1979.77	3.05465482E 07	4.22653096E 11	45.52
93	1934.24	3.10553302E 07	4.27325896E 11	45.53
94	1888.69	3.15668727E 07	4.31998696E 11	45.55
95	1843.09	3.20811827E 07	4.36671496E 11	45.60
96	1797.46	3.25982721E 07	4.41344296E 11	45.63
97	1751.76	3.31181457E 07	4.46017096E 11	45.70
98	1705.96	3.36408157E 07	4.50689896E 11	45.80
99	1660.09	3.41662966E 07	4.55362696E 11	45.87
100	1614.10	3.46945965E 07	4.60035496E 11	45.99
101	1568.00	3.52257331E 07	4.64708296E 11	46.10
102	1521.77	3.57597186E 07	4.69381096E 11	46.23
103	1475.36	3.62965691E 07	4.74053896E 11	46.41
104	1428.76	3.68363065E 07	4.78726696E 11	46.60
105	1382.01	3.73789519E 07	4.83399496E 11	46.75
106	1335.01	3.79245192E 07	4.88072296E 11	47.00
107	1287.81	3.84730397E 07	4.92745096E 11	47.20
108	1240.39	3.90245323E 07	4.97417896E 11	47.42
109	1192.68	3.95790186E 07	5.02090696E 11	47.71
110	1144.68	4.01365305E 07	5.06763496E 11	48.00
111	1096.38	4.06970957E 07	5.11436296E 11	48.30
112	1047.78	4.12607427E 07	5.16109096E 11	48.60
113	998.79	4.18275004E 07	5.20781896E 11	48.99
114	949.48	4.23974101E 07	5.25454696E 11	49.31
115	899.74	4.29704978E 07	5.30127496E 11	49.74
116	849.62	4.35468084E 07	5.34800296E 11	50.12
117	799.02	4.41263736E 07	5.39473096E 11	50.60
118	747.99	4.47092427E 07	5.44145896E 11	51.03
119	696.45	4.52954528E 07	5.48818696E 11	51.54
120	644.35	4.58850553E 07	5.53491496E 11	52.10
121	591.74	4.64781051E 07	5.58164296E 11	52.61
122	538.51	4.70746455E 07	5.62837096E 11	53.23
123	484.66	4.76747371E 07	5.67509896E 11	53.85
124	430.14	4.82784344E 07	5.72182696E 11	54.52
125	374.92	4.88857997E 07	5.76855496E 11	55.22
126	318.93	4.94968966E 07	5.81528296E 11	55.99
127	262.20	5.01117984E 07	5.86201096E 11	56.73
128	204.60	5.07305695E 07	5.90873896E 11	57.60
129	146.12	5.13532948E 07	5.95546696E 11	58.48

130	86.70	5.19800526E 07	6.00219496E 11	59.42
131	26.28	5.26109289E 07	6.04892296E 11	60.42
132	-35.20	5.32460162E 07	6.09565096E 11	61.48

RESERVOIR DEPLETED

VITA

Ossian R. Butterfield was born at Leominster, Massachusetts, on May 12, 1927, the son of Ossian R. and Helen P. Butterfield. He attended public schools in Leominster, graduating from Leominster High School in 1944. He entered the U. S. Navy in June, 1944, was enrolled in the Navy V-12 College Training Program and attended Williams College in Williamstown, Massachusetts. In November, 1945, he was transferred to the U.S. Naval Reserve Officers Training Course Unit at Brown University. In 1947, he was graduated from Brown with the degree of Bachelor of Science in Engineering. Upon graduation, he was commissioned an Ensign in the U.S. Navy Civil Engineering Corps. Duty assignments have included engineering duties at the Naval Proving Grounds, Dahlgren, Virginia; the Naval Air Station, Dallas, Texas; the Naval Stations in Argentia, Newfoundland, and in Bermuda, The West Indies; the Naval Air Station, Patuxent River, Maryland; the Naval Radio Station, Kamiseya, Japan; and the Naval Mine Warfare School, Yorktown, Virginia. In 1955 and 1956 he attended Rensselaer Polytechnic Institute in Troy, New York, where he received the Bachelor of Civil Engineering degree in June 1956. He has served as Executive Officer and as Commanding Officer of U.S. Naval Mobile Construction Battalion Six deployed to Rota, Spain, and other bases in the Atlantic Ocean

Area. His most recent duty assignment was in the Bureau of Yards and Docks, Navy Department, Washington, D.C., where he was Director of the Construction Division responsible for the management of projects engineered and constructed by the U.S. Navy for other governmental agencies.

He was selected for postgraduate education in petroleum engineering and entered the Graduate School of The University of Texas in September, 1963.

Butterfield was married to Ann Churchill of King George, Virginia, on April 11, 1950. They have two children, Marcia, age 13, and Brian, age 12.

Permanent address: 6600 Willamette Drive
Austin, Texas

This thesis was typed by Virginia F. Dailey.